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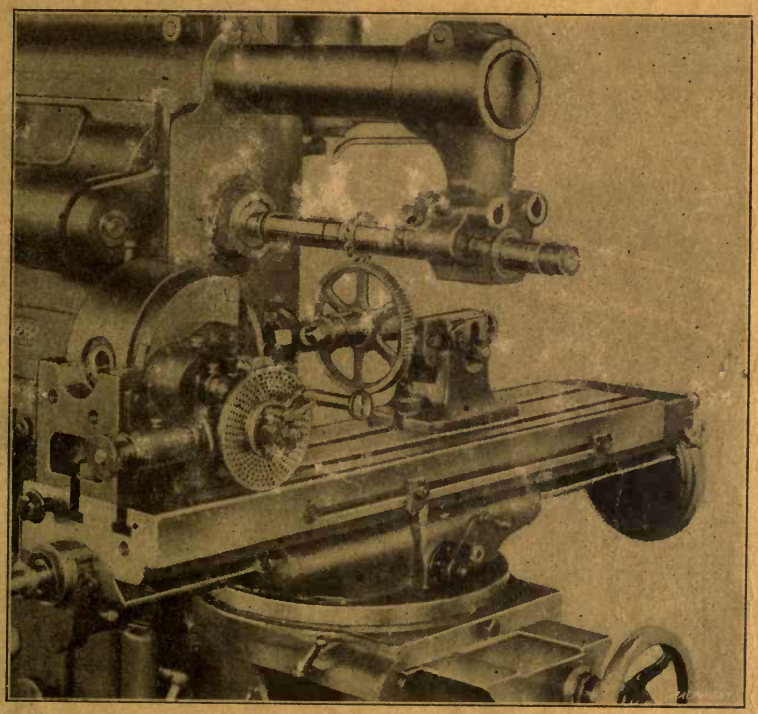
# SHOP ARITHMETIC
## FOR THE MACHINIST

BY ERIK OBERG

FIFTH EDITION



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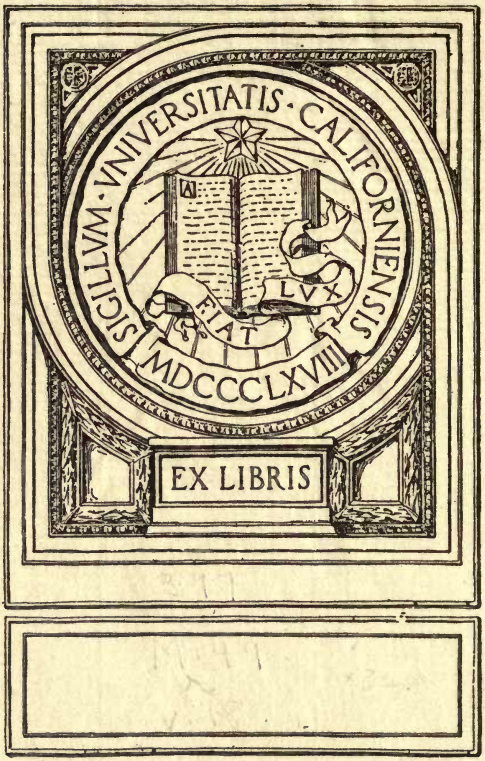
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NUMBER 18

# SHOP ARITHMETIC FOR THE MACHINIST

By ERIK OBERG

FIFTH REVISED EDITION

TOTAL ISSUE—FORTY-TWO THOUSAND COPIES

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When preparing the third edition of this Reference Series book, a considerable amount of matter pertaining directly to general shop calculations was added. In order to provide space for this material, the chapters on more advanced shop calculations, including Square and Square Root, Use of Formulas, and Use of Tables of Sines, Cosines, Tangents and Cotangents, were omitted, and are, together with additional matter of an advanced nature, included in MACHINERY'S Reference Series No. 52, Advanced Shop Arithmetic for the Machinist.

# INTRODUCTION

In the following, some of the most common shop subjects requiring simple calculations have been treated, and special efforts have been made to treat each subject as simply as possible, so that the present treatise may be of service to those, particularly, who have not previously acquired a great amount of knowledge about handling figures, and who are not familiar with mathematical expressions and usages. In order to fix the processes and rules more firmly in the reader's mind, examples have been given in almost all instances, and in many cases a number of similar examples have been given, so as to permit the repetition of the same calculation a number of times. Practically all formulas have been written out in words, as this gives a better idea about what the formula actually means, at least to those not familiar with engineering handbooks. Mathematical signs have also been avoided to a certain extent, and the corresponding words have been written out in full. In short, all precautions have been taken to present the methods in as plain and simple language as possible. Many text-books deal with principles rather than with specific examples, and to a person who is not used to solving problems of the kind that are met with in the machine shop, it is often difficult to apply the principles involved to each particular case. The purpose of this book has, therefore, been to select the most common specific cases, and to show directly how the principles are applied.

While the subject in hand has been treated to accommodate the requirements of those who demand a book that is plain and simple, it has been necessary to presuppose fundamental knowledge in regard to the use of numbers in calculations, that is, the reader must be fairly competent to add, subtract, multiply, and divide whole numbers and decimals, and also have some fundamental ideas of the use of common fractions.* If such knowledge has been acquired, no difficulty will be experienced in making use of the rules and formulas given.

It is assumed that the reader is familiar with the common mathematical signs, + (plus) which signifies addition, — (minus) which signifies subtraction, × (times) which signifies multiplication, and ÷ (divided by) which signifies division, as well as with the sign = (equals) which is put between quantities which are equal to one another to signify this condition. But it may be appropriate to call attention to the different methods commonly used for indicating division, as these may not be clear to all. Usually, as we already have said, in arithmetic, division is indicated by the sign ÷, so that we have, for instance,

$$12 \div 3 = 4.$$

A more common method in engineering books, however, is to simply

* For a simple treatise on these elements, see MACHINERY'S Jig Sheets Nos. 1A to 15A, inclusive.

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write the dividend as the numerator of a fraction and the divisor as the denominator, thus:

$$\frac{12}{3}=4.$$

In that case the fraction indicates a division. This system will be followed in many of the following formulas, and it should therefore be remembered that *the line between the numerator and denominator in a fraction always indicates a division, the numerator to be divided by the denominator.*

The actual division, however, is not necessarily worked out in every case where division is thus implied. When two divisions are multiplied together, cancellation and the following operations of addition or subtraction may make the actual numerical work very simple.

Although knowledge of common fractions is presupposed, it may be well at this point to repeat the rules for multiplication and division of common fractions, as in the following many operations of this kind must be made. Two fractions are multiplied by multiplying numerator by numerator and denominator by denominator, (*numerator* being the *upper*, and *denominator* the *lower* quantity in a fraction). For instance, let it be required to multiply ¼ by ⅜. We have then,

$$\frac{1}{4}\times\frac{3}{8}=\frac{1\times 3}{4\times 8}=\frac{3}{32}$$

If the numbers to be multiplied contain whole numbers, these are first converted into fractions. Let it be required to multiply 1¼ by 3¼. We have then,

$$1\frac{1}{4}\times 3\frac{1}{4}=\frac{5}{4}\times\frac{13}{4}=\frac{65}{16}=4\frac{1}{16}$$

Division is simply the reverse of multiplication. The number which is to be divided is called the *dividend*, and the number by which we divide is called the *divisor*. If one number is to be divided by another, we simply invert the divisor, and *proceed as in multiplication.* To invert the divisor means that we place the denominator as numerator, and the numerator as denominator; for instance, 3/8, inverted, is 8/3. Suppose that we wish to divide 3/4 by 7/16. We have then,

$$\frac{3}{4}\div\frac{7}{16}=\frac{3}{4}\times\frac{16}{7}=\frac{48}{28}=1\frac{20}{28}=1\frac{5}{7}$$

If the number to be divided contains a whole number besides a fraction, we first convert this into a fraction, and then proceed as before. Suppose that we wish to divide 2¼ by 3¾. We have then,

$$2\frac{1}{4}\div 3\frac{3}{4}=\frac{9}{4}\div\frac{15}{4}=\frac{9}{4}\times\frac{4}{15}=\frac{36}{60}=\frac{3}{5}$$

A parenthesis about a mathematical expression indicates that the calculation enclosed by the parenthesis is to be carried out before the other calculations in the example; thus, $(5+8)\times 2=13\times 2=26$, but $5+(8\times 2)=5+16=21$.

# CHAPTER I

## FIGURING TAPERS

In all circular or round pieces of work, the expressions "taper per inch" and "taper per foot" mean the taper on the *diameter*, or the difference between the smaller and the larger diameter of a piece, measured one inch or one foot apart, as the case may be. Suppose in Fig. 1 that the diameter at *A* is one inch, and the diameter at *B*, one and one-half inch, and that the distance or dimension between *A* and *B* is 12 inches or one foot. This piece, then, tapers one-half inch per foot, because the difference between the diameters at *A* and *B* is one-half inch. In Fig. 2, the diameter at *C* is 7/16 inch, and at *D*, 1/2 inch, and the distance between *C* and *D* is one inch. This piece, therefore, tapers 1/16 inch per inch. Tapers may also be expressed for other lengths than one inch and one foot. In Fig. 3, the diameter at *E* is 1 1/8 inch, and at *F*, 1 9/32 inch, and the dimension from *E* to *F* is 5 inches. This piece of work, therefore, tapers 5/32 inch in 5 inches, the difference between 1 9/32 and 1 1/8 being 5/32.

If the taper in a certain number of inches is known, the taper in 1 inch can easily be found. If the taper in 5 inches is 5/32 inch, the taper in 1 inch equals the taper in 5 inches divided by 5, or, in this case, $5/32 \div 5 = 1/32$, which is the taper per inch. The taper per foot is found by multiplying the taper per inch by 12. In this case, the taper per foot equals $12 \times 1/32 = 3/8$ inch. The length of the work is always measured parallel to the center line (axis) of the work, and never along the tapered surface.

The problems met with in regard to figuring tapers may be of three classes. In the first place we may have given us the figures for the large and small ends of a piece of work, and the length of the work, as in Fig. 4, and we want to find the taper per foot. In the second place we may know the diameter at one end, the length of the work, and the taper per foot, as in Fig. 5, and we want to find the diameter at the other end of the work. In the third place we may know the required diameters at both ends of the work, and the taper per foot, as in Fig. 6, and we want to find the dimension between the given diameters, or the length of the piece. We will now treat each of these problems in detail.

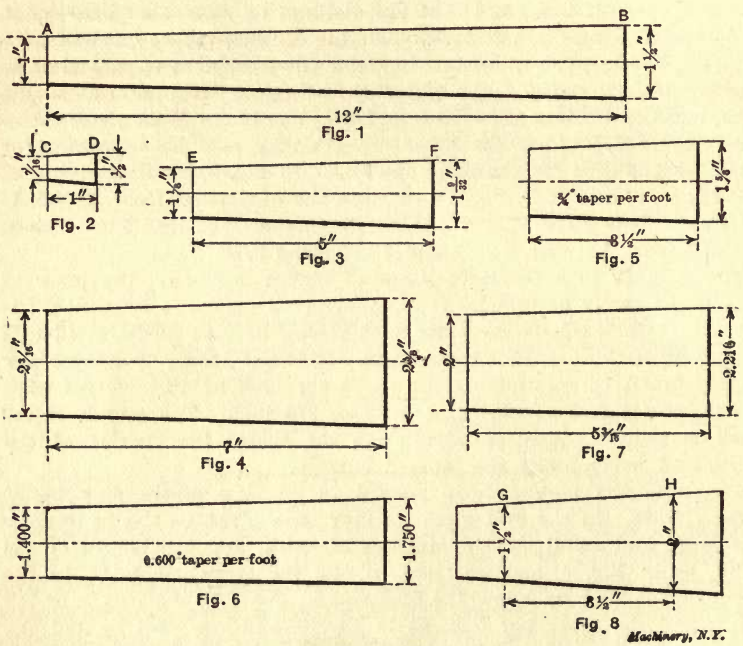
1. *To find the taper per foot when the diameters at the large and small ends of the work, and the length, are given.*

Referring to Fig. 4, the diameter at the large end of the work is 2 5/8 inches, the diameter at the small end, 2 3/16 inches, and the length of the work 7 inches. The taper in 7 inches is then equal to the difference between 2 5/8 inches and 2 3/16 inches, or 7/16 inch. The taper in one inch equals 7/16 divided by 7, or 1/16 inch; and the taper per foot is 12 times the taper per inch, or 12 times 1/16, which equals 3/4 inch. The taper per foot in Fig. 4, then, equals 3/4 inch.

If the dimension between the small and the large diameter is not expressed in even inches, but is 5 3/16 inches, for instance, as in Fig. 7, the procedure is exactly the same. Here the diameter at the large end is 2.216 inches and at the small end 2 inches. The taper in 5 3/16 inches is, therefore, 0.216 inch. This is divided by 5 3/16 to find the taper per inch.

$$0.216 \div 5\frac{3}{16} = 0.216 \div \frac{83}{16} = 0.216 \times \frac{16}{83} = 0.0416.$$

The taper per inch, consequently equals 0.0416 inch, and the taper per foot is 12 times this amount, or almost exactly ½ inch.




Figs. 1 to 8

Expressed as a formula, if all dimensions given are in *inches*, the previous calculation would take this form:

$$\text{taper per foot} = \frac{\text{large dia.—small dia.}}{\text{length of work}} \times 12.$$

It makes, of course, no difference if the large and small diameters are measured at the extreme ends of the work or at some other place on the work, provided the length or distance between the points where the diameters are given, is stated. In Fig. 8, the smaller and larger diameters are given at certain distances from the ends of the work, but the dimension from *G* to *H* is given, and the calculation is exactly the same as if the work were no longer than between *G* and *H*. The

following examples will tend to show how the figuring of the taper per foot enters in actual shop work.

*Example* 1.—Fig. 9 shows the blank for a taper reamer. The diameters at the large and small ends of the flutes, and the length of the fluted part, are stated on the drawing. It is required to find the taper per foot in order to be able to set the taper turning attachment of the lathe.

Referring to the figures given in Fig. 9, the difference in diameters at the large and small ends of the taper is 15/64 inch. This divided by the length of the flute, 7½ inches, gives us the taper per inch. This we find to be 1/32. The taper per foot is 12 times the taper per inch, or, in this case, then, ⅜ inch. The taper attachment of the lathe is, therefore, set to the ⅜-inch graduation, and the taper turned will be according to the diameters given on the drawing.

*Example* 2.—Fig. 10 shows a taper clamping bolt, entering into the design of a special machine tool. As seen from the cut, the drawing

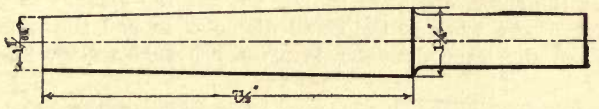


FIG. 9

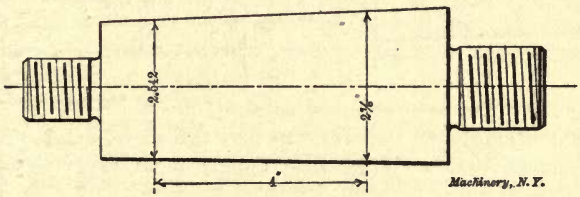



FIG. 10

Figs. 9 and 10

calls for a diameter of 2⅞ inches a certain distance from the large end of the taper, and for a diameter of 2.542 inches a distance 4 inches further down on the taper. The taper in 4 inches is then 2⅞ inches minus 2.542 inches, or 0.333 inch. The taper in one inch equals this divided by 4, or 0.0833. The taper per foot is 12 times the taper per inch, or 12 times 0.0833, which equals one inch, almost exactly. The taper to which to turn the bolt in Fig. 10 is thus one inch per foot.

2. *If the diameter at one end of the taper is given, and also the length of the work and the taper per foot, to find the diameter at the other end of the work.*

Referring to Fig. 5, the diameter at the large end of the work is 1⅝ inch, the length of the work is 3½ inches, and the taper per foot is ¾ inch. We now want to find the diameter at the small end. In this case we simply reverse the method employed in our previous problems, where we wanted to find the taper per foot. In this case we know that the taper per foot is equal to ¾ inch. The taper in one

inch must be one-twelfth of this, or ¾ inch divided by 12, which equals 1/16 inch. Now, the taper in 3½ inches, which we want to find in order to know what the diameter is at the small end of the work, must be 3½ times the taper in *one* inch, or 3½ times 1/16, which equals 7/32. The taper in 3½ inches, then, is 7/32 inch, which means that the diameter at the small end of a piece of work, 3½ inches long, is 7/32 inch smaller than the diameter at the large end. The diameter at the large end, according to our drawing, is 1⅝ inch. The diameter at the small end, being 7/32 inch smaller, is therefore 1 13/32 inch.

Expressed as a formula, the previous calculation would take this form:

$$\text{dia. at small end} = \text{dia. at large end} - \left(\frac{\text{taper per foot}}{12} \times \text{length of work}\right)$$

If we now take a case where the diameter at the small end is given, as in Fig. 11, and the diameter at the large end is wanted, the figuring is exactly the same, except of course, we *add* the amount of taper in the length of the work to the small diameter to find the large diameter. When the large diameter is given, we *subtract* the amount of

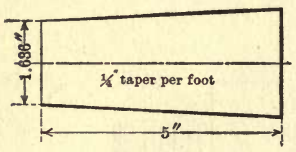



Fig. 11

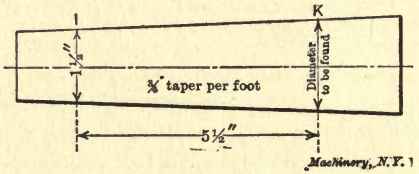



Fig. 12

taper in the length of the work to find the small diameter. This is so self-evident that no difficulties ought to be experienced on this account.

Referring again to Fig. 11, where the small diameter is given as 1.636 inch, the length of the work as 5 inches, and the taper per foot as ¼ inch, how large is the large diameter of the work? If the taper per foot is ¼ inch, the taper per inch is ¼ divided by 12 which equals 0.0208, and the taper in 5 inches consequently 5 times 0.0208, or 0.104 inch. The diameter at the large end of the work, which we are figuring, is, then, 0.104 inch larger than the diameter at the small end. The diameter at the small end is given on the drawing as 1.636 inch; adding 0.104 inch to this, we get 1.740 inch as the diameter at the large end.

Expressed as a formula, the previous calculation would take this form:

$$\text{dia. at large end} = \text{dia. at small end} + \left(\frac{\text{taper per foot}}{12} \times \text{length of work}\right)$$

It may again be well to call attention to the fact that it makes no difference whether the large and small diameters are figured at the extreme ends of the work or at some other points, as long as the

diameter to be found is located at one end of the length dimension, and the diameter stated on the drawing at the other. Thus, in Fig 12 the diameter stated at *I* is given a certain distance up on the taper, and the diameter at *K*, which is wanted, is not at the end of the taper. But the dimension 5½ is given between the points *I* and *K* where these diameters are to be measured, and in figuring, one may reason as if the work ended at *I* and *K*, the diameter at *I* being the small diameter, the diameter at *K*, the large diameter, and 5½ inches the total length of the work. The following examples of direct practical application to shop work will prove helpful in remembering the principles outlined.

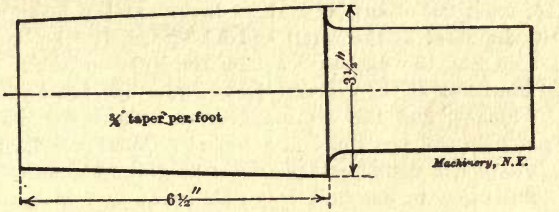



Fig. 13

*Example* 1.—Fig. 13 shows a taper tap, the blank for which is to be turned. The diameter at the large end of the threaded part is 3½ inches, as given on the drawing, the length of the thread is 6½ inches, and the taper per foot is ¾ inch. We want to find the diameter at the small end, in order to measure this end and ascertain that the tap blank has been correctly turned.

The taper per foot being 3/4 inch, the taper per inch is 3/4 divided by 12, or 1/16 inch. The taper in 6 1/2 inches is 6 1/2 times the taper in one inch, or 6 1/2 times 1/16 inch, which equals 13/32 inch. The taper in 6 1/2 inches being 13/32 inch means that the diameter at the small end of the tap blank is 13/32 inch smaller than the diameter at the

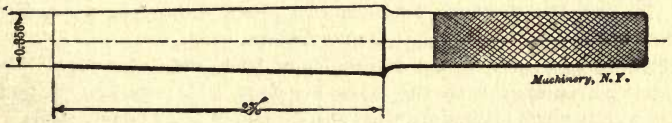



Fig. 14

large end. The diameter at the small end is, therefore, 3 3/32 inches.

*Example* 2.—Fig. 14 shows a taper gage for a standard Morse taper No. 1. The diameter at the small end is 0.356 inch, the length of the gage part is 2⅜ inches, and the taper per foot 0.600 inch. We want the diameter at the large end, in the first place in order to know what size stock to use for the gage, and later for measuring this diameter, when turned, to see that the taper turned is correct.

A taper of 0.600 per foot gives us a taper of 0.050 per inch. In 2⅜ inches the taper equals 2⅜ times 0.050, or 0.119 inch. This added to the diameter at the small end gives us the diameter at the large end: $0.356 + 0.119 = 0.475$ inch.

*Example* 3.—Fig. 15 shows a taper bolt used as a clamp bolt. The diameter 3¼ inches is given 3 inches from the large end of the taper. The total length of the taper is 10 inches. The taper is ⅜ inch per foot. We want to find the diameters at the extreme large and small ends of this piece.

We will first find the diameter at the large end. The taper per foot being ⅜ inch, the taper per inch equals 1/32 inch. The taper in 3 inches is consequently 3/32. This added to 3¼ inches will give us the diameter at the large end, which is 3 11/32 inches.

To find the diameter at the small end, subtract the taper in 10 inches, which is 10 times the taper in one inch, or 10 times 1/32, which equals 5/16, from the diameter 3 11/32 inches at the large end. This gives us the diameter at the small end 3 1/32 inches.

We can also find the diameter at the small end without previously finding the diameter at the extreme large end. The total length of the taper is 10 inches, and the dimension from where the diameter 3¼ inches is given to the large end is 3 inches. Consequently, the dimension from where the diameter 3¼ inches is given to the small end is 7 inches. The taper in one inch was 1/32 inch; in 7 inches, therefore,

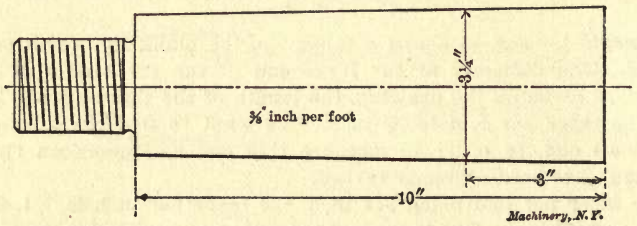



Fig. 15

7/32 inch. The diameter at the small end of the work is 7/32 inch smaller than 3¼ inches, or 3 1/32 inches, the same as found previously when we figured from the extreme large diameter of the taper.

3. *To find the distance between two given diameters on a tapered piece of work, if the taper per foot is known.*

Referring to Fig. 6, if the diameters at both ends of a tapered piece are known, together with the taper per foot, it is required to find the length of the work. Assume that the diameter at the large end of the piece is 1.750 inch, and at the small end, 1.400 inch. The taper per foot is 0.600 inch. How long is this piece of work required to be, in order to have the given diameters at the ends, with the taper stated? We know that the taper per foot is 0.600 inch. The taper per inch is then 0.600 divided by 12, or 0.050 inch. The difference in diameters between the large and the small ends of the work is 1.750 — 1.400, or 0.350 inch, which represents the taper in the length of the work. Now, we know that the taper is 0.050 inch in *one* inch. How many inches does it then require to get a taper of 0.350 inch? This we find by seeing how many times 0.050 is contained in 0.350, or, in other words, by dividing 0.350 by 0.050, which gives us 7 as answer. This means that it takes 7 inches for a piece of work to taper 0.350 inch,

if the taper is 0.600 per foot. The length of the work consequently is 7 inches in the case referred to.

Expressed as a formula the previous calculation would take the form:

$$\text{length of work} = \frac{\text{dia. at large end} - \text{dia. at small end}}{\text{taper per foot} \div 12}$$

The taper per foot divided by 12, as given in the formula above, of course simply represents the taper per inch. The formula may therefore be written:

$$\text{length of work} = \frac{\text{dia. at large end} - \text{dia. at small end}}{\text{taper per inch}}$$

A few examples of the application of these rules will make their use in actual shop work clearer.

*Example* 1.—A taper reamer, Fig. 16, for standard taper pins, having ¼ inch taper per foot, is to be made. The diameter at the large end of the flutes is wanted to be 0.720 inch. The diameter at the point of the reamer must be 0.580 inch, in order to accommodate the longest

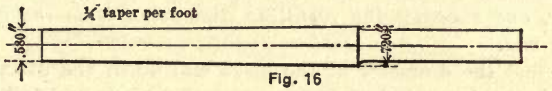



Fig. 16

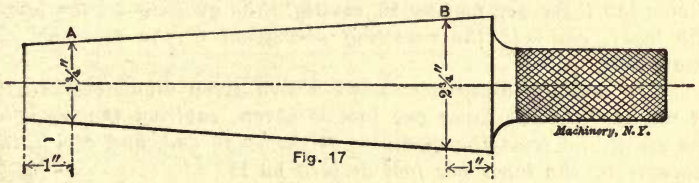



Fig. 17

Figs. 16 and 17

taper pins of this size made. How long should the fluted part of the reamer be made?

The taper per foot is ¼ or 0.250 inch, and the taper per inch, consequently, 0.250 divided by 12, or 0.0208 inch. The taper in the length of reamer required is equal to the difference between the large and the small diameter, or 0.720 — 0.580 equals 0.140 inch. This amount of taper divided by the taper in one inch gives the required length of the flutes. Thus, 0.140, divided by 0.0208 equals 6.731, which represents the length of flutes required. This dimension is nearly 6¾ inches, and, being a length dimension of no particular importance, it would be made to an even fractional part of an inch.

*Example* 2.—In Fig. 17 is shown a taper master gage intended for inspecting taper ring gages of various dimensions. The smallest diameter of the smallest ring gage is 1¾ inch, and the largest diameter of the largest ring gage is 2¾ inches. The taper per foot is 1½ inch. It is required that the master gage extends one inch outside of the gages at both the small and the large ends, when these are tested. How long should the gage portion of this piece of work be?

The taper per foot is 1½ inch, which is equivalent to ⅛ inch taper per inch. The total taper from *A* to *B* in Fig. 17 is 2¾ minus 1¾, or one inch. Therefore, as the taper per inch, ⅛, is contained in the taper of one inch in the distance from *A* to *B* exactly 8 times, the dimension from *A* to *B* is 8 inches. The gage extends one inch beyond *A* and *B*, respectively, at either end, and the total length of the gage is, therefore, 10 inches.

### Rules for Figuring Tapers

1. If the taper per foot is known, the taper per inch is found by *dividing the taper per foot by* 12.

2. If the taper per inch is known, the taper per foot is found by *multiplying the taper per inch by* 12.

3. To find the taper per foot, when the diameters at the large and small ends and the length of the taper are given, *substract the small diameter from the large, divide the remainder by the length of the taper, and multiply the quotient by* 12.

4. To find the diameter at the small end when the diameter at the large end, the length of the taper, and the taper per foot are given, *divide the taper per foot by* 12, *multiply the quotient by the length of the taper, and subtract the resulting dimension from the diameter at the large end.*

5. To find the diameter at the large end when the diameter at the small end, the length of the taper, and the taper per foot are given, *divide the taper per foot by* 12, *multiply the quotient by the length of the taper, and add the resulting dimension to the diameter at the small end.*

6. To find the dimension between two given diameters of a piece of work, when the taper per foot is given, *subtract the diameter at the small end from the diameter at the large end, and divide the remainder by the taper per foot divided by* 12.

7. To find how much a piece of work tapers in a certain length, when the taper per foot is given, *divide the taper per foot by* 12, *and multiply the quotient by the dimension of the certain length in which the taper is required.*

## CHAPTER II

### SETTING OVER TAIL-STOCK FOR TAPER TURNING

The live center and the tail center in a lathe are in alignment when a cutting tool, held in the tool-post of the lathe carriage, traverses in a direction parallel to a line connecting the points of the two centers; if a piece of work is then placed between the centers and revolved, and a cut taken over it, a cylindrical ("straight") piece will be turned. If the tail center is moved out of alignment with the live center an amount *A*, as shown in Fig. 18, then the center of the work at the tail center end will come nearer to the line of traverse *BC* of the tool than the center of the work at the live center end, and the diameter of the piece, when turned, will be smaller at the tail center than at the live center. It is therefore a common method to set over the tail-stock when a tapered piece is to be turned. The amount of the taper de-

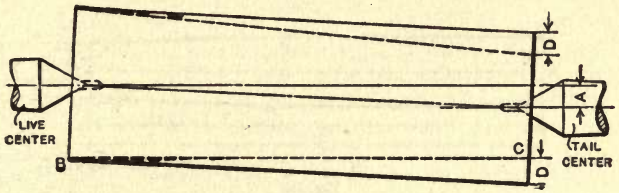



Fig. 18

pends on the length of the work and the "set-over" of the tail center in each case.

When the tail center is set over an amount *A*, as shown in Fig. 18, the radius (one-half of the diameter) at the small end will be a dimension *D* smaller than the radius at the large end. This dimension *D* is also equal to the amount *A* which the tail center has been set over, and the taper of the work in the length between the centers, therefore, is two times the amount the tail-stock is set over; or, in other words, the tail-stock is set over one-half of the taper in the length of the work.

#### Taper per Foot and the Length are Known

The amount which the tail-stock must be set over can be determined if the taper per foot of the work and the length are known.

Assume that a piece of work, 7½ inches long, is required to be turned with a taper per foot equal to ¾ inch. We must first know how much the work tapers in 7½ inches. This we find by dividing ¾ by 12, and multiplying the quotient by 7½ (see page 12, Rule 7).

$$(¾ \div 12) \times 7½ = 15/32.$$

The taper in 7½ inches thus is 15/32 inch, and as the tail-stock is moved one-half of this, it is set over 15/64 inch.

When the taper per foot and the length of the work are given, we can calculate the amount to set over the tail-stock from the following formula:

$$\text{amount to set over tail-stock} = \tfrac{1}{2} \times \left( \frac{\text{taper per foot}}{12} \times \text{length of work} \right)$$

Expressed in words, this formula reads:

To find the amount to set over the tail-stock when the taper per foot and the length of the work are known, *divide the taper per foot by* 12, *multiply the quotient by the length of the work, and divide the result by* 2. (To divide by 2 is the same as to multiply by ½.)

Owing to the fact that the work is not supported by the lathe centers at its extreme ends, but that the lathe centers enter into the work and support it at points a short distance from the ends, it is not practicable to calculate the amount to set over the tail-stock so definitely that the taper can be turned to exact dimensions without a trial cut; but the calculation for setting over the tail-stock gives a close approximation,

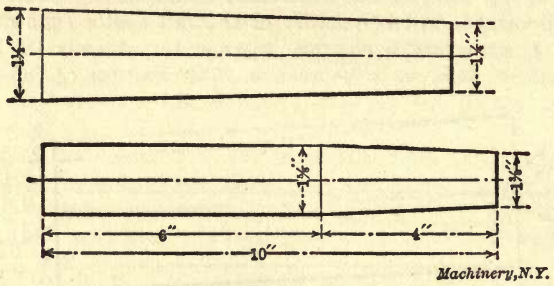



Fig. 20

and when a trial cut on the work has been taken, the final adjustment of the tail-stock to obtain the correct taper can be easily made.

### Method Used when the Diameters at Both Ends of a Tapered Piece are Known

If the diameters at both the large and small ends of work tapering for its full length, are given, the amount to set over the tail-stock can be determined without knowing the taper per foot, because all that is necessary to know is the taper in the length between the centers of the lathe. If, for instance, the diameter at the large end of the work is 1½ inch and the diameter at the small end 1¼ inch, as shown in Fig. 19, the amount to set over the tail-stock will be one-half of the difference between the large and small diameters, or ⅛ inch. When the diameters at the large and small ends are known, the following formula is therefore used:

amount to set over tail-stock = ½ × (large diameter—small diameter).

Expressed in words, this formula reads:

To find the amount to set over the tail-stock for work tapering for its full length, when the diameters at the large and small ends are known, *subtract the small diameter from the large, and divide the remainder by* 2.

**Method Used when Part of the Work is Turned Straight and Part Tapered**

If part of the work is turned straight and part of it turned tapered, as shown in Fig. 20, the taper in the whole length of the work must be determined, and then the tail-stock set over one-half of this amount. In Fig. 20 the work shown is 1⅜ inch at the small end of the taper. It is tapered for 4 inches, and the diameter at the large end of the taper is 1⅝ inch. It is then turned straight for the remaining 6 inches, the total length being 10 inches. We must first find what the taper would be in 10 inches if the whole piece had been tapered with the same taper as now required for 4 inches. The taper in 4 inches is $1\frac{5}{8} - 1\frac{3}{8} = \frac{1}{4}$ inch. The taper in 1 inch, consequently, is 1/16 inch, and in 10 inches, $10 \times 1/16 = \frac{5}{8}$ inch. The amount to set over the tail-stock is one-half of this, or 5/16 inch.

If, in a case as shown in Fig. 20, the diameter at the small end is not given, but the taper per foot of the tapered part stated instead,

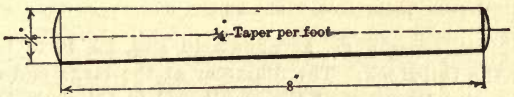



Fig. 21

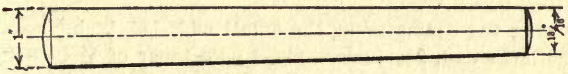


Fig. 22

the taper in the total length of the work can be found directly; if the taper per foot be ¾ inch, the taper in 10 inches is $(\frac{3}{4} \div 12) \times 10 = \frac{5}{8}$ inch. (See page 12, Rule 7.) The amount to set over the tail-stock, consequently, is 5/16 inch. The following formula is used when part of the work is turned straight and part tapered:

$$\text{amount to set over tail-stock} = \tfrac{1}{2} \times \left( \frac{\text{taper per foot}}{12} \times \text{total length of work} \right)$$

Expressed as a rule, this formula would read:

To find the amount to set over the tail-stock for work partly tapered and partly straight, when the taper per foot and the total length of the work are known *divide the taper per foot by* 12, *multiply the quotient thus obtained by the total length of the work, and divide by* 2.

If the taper per foot is not given, it must be found before using this formula and rule. (See page 12, Rule 3.)

The following examples will help to give a clear idea of the application of these rules.

*Example* 1.—The taper pin shown in Fig. 21 is 8 inches long, and tapers ¼ inch per foot. How much should the tail-stock be set over when turning this pin?

Dividing the taper per foot by 12 gives us 0.0208. Multiplying this figure (which represents the taper per inch) by 8 gives us 0.166 as

the taper in 8 inches. Dividing this by 2 gives us the amount required to set over the tail-stock. This amount then is 0.083 inch.

*Example* 2.—Another taper pin, Fig. 22, is 1 inch in diameter at the large end, and 13/16 inch at the small end. How much should the tail-stock be set over for turning this pin?

The total taper of this pin is found by subtracting the diameter at the small end, 13/16 inch, from the diameter at the large end, 1 inch. This gives us a remainder of 3/16. One-half of this amount, or 3/32 inch, represents the amount which the tail-stock should be set over.

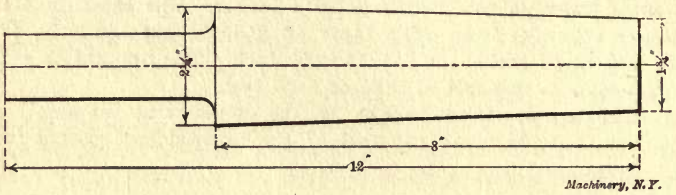



Fig. 23

*Example* 3.—A taper gage, as shown in Fig. 23, is to be turned by setting over the tail-stock. The diameter at the large end of the taper is 2¼ inches, the diameter at the small end is 1¾ inch, the length of the taper, 8 inches, and the total length, 12 inches. How much should the tail-stock be set over?

Subtracting the diameter at the small end, 1¾ inch, from the diameter at the large end, 2¼ inches, gives us a taper of ½ inch in 8 inches. Dividing ½ by 8, gives us the taper in one inch, which is 1/16 inch. Multiplying this by the total length of the work, 12 inches, gives us ¾ inch, which, divided by 2, gives us, finally, the required amount which the tail-stock is to be set over. This latter is, therefore, set over ⅜ inch.

## CHAPTER III

## CUTTING SPEEDS AND FEEDS

The cutting speed of a tool is the distance in feet which the tool point cuts in one minute; thus, if the point of a lathe tool cuts 40 feet, measured around the work, on the surface of a casting turned in the lathe, in one minute, we say that the cutting speed is 40 feet per minute.

On the planer, the cutting speed is equal to the length of cut that would be taken in one minute. If a cut 12 feet long is taken in 20 seconds, then, as 20 seconds is one-third of a minute, a cut 36 feet long could be made with the same speed in one minute, and the cutting speed is 36 feet per minute.

When drilling a hole in the drill press, the cutting speed is the number of feet that the outer corners of the cutting edges travel in one minute.

### Cutting Speeds in the Lathe, Boring and Turning Mill and Drill Press

The problems in regard to cutting speeds in the lathe or turning and boring mill may be divided in two groups.

1. *The diameter of the work turned in a lathe or boring mill and the required cutting speed are known. How many revolutions per minute should the work make?*

Assume that the diameter of the work is 5 inches, and the required cutting speed 40 feet per minute. When the diameter of the work is known, its circumference equals the diameter times 3.1416. Therefore the circumference of the work in this case is $5 \times 3.1416 = 15.708$ inches. For calculations of this character it will be near enough to say that the circumference is 15.7 inches. For each revolution of the work, the length of its circumference passes the tool point once; thus for each revolution, a length of 15.7 inches passes the tool. As the cutting speed is expressed in feet, the length 15.7 inches should also be expressed in feet, which is done by dividing by 12, thus obtaining $15.7 \div 12 = 1.308$ foot, as the circumference of the work. The next question is, how many revolutions, each equivalent to 1.308 foot, does it require to get a cutting speed of 40 feet. This we get by finding how many times 1.308 is contained in 40, or, in other words, by dividing 40 by 1.308. The quotient of this division is 30.6. Therefore, 30.6 revolutions per minute are required to obtain a cutting speed of 40 feet per minute in this case.

This calculation is expressed by the formula:

$$\text{revolutions per minute} = \frac{\text{cutting speed in feet per minute}}{\left(\begin{matrix}\text{diameter of}\\ \text{work in inches}\end{matrix} \times 3.1416\right) \div 12}$$

If instead of turning work 5 inches in diameter, a hole 5 inches in diameter is to be bored by an ordinary forged boring tool or a tool inserted into a boring bar, and the cutting speed is required to be 40 feet per minute, the calculation for the revolutions per minute is carried out in the same manner as mentioned before, and the same formula is used, except that in the formula we write "diameter of hole to be bored in inches" instead of "diameter of work in inches."

For work done in the drill press, the formula can also be used by substituting "diameter of hole to be drilled in inches" for "diameter of work in inches."

2. *The number of revolutions which the work makes in a lathe or boring mill, and the diameter are known. What is the cutting speed?*

A brass rod one inch in diameter is being turned. By counting the number of revolutions of the spindle of the lathe by means of a speed indicator (instrument for counting the number of revolutions of revolving shafts or spindles) it is found that the work revolves 382 revolutions per minute. To find the cutting speed, the circumference

of the work is first figured and changed into feet. The circumference in inches is $1 \times 3.1416 = 3.1416$, and $3.1416 \div 12 = 0.262$, the circumference in feet, or the distance passed over by the tool point for each revolution. During 382 revolutions, the distance passed over is $382 \times 0.262 = 100$ feet, which thus is the cutting speed per minute.

This calculation is expressed by the formula:

$$\text{cutting speed in feet per minute} = \frac{\text{dia. of work in inches} \times 3.1416}{12} \times \text{revolutions per minute}$$

If in this formula "diam. of work in inches" is substituted by "diameter of bored or drilled hole in inches," the formula can be used for cutting speeds of drills and boring tools also.

(If the cut taken on a piece being turned is deep in proportion to the diameter of the work, it is preferable in calculations for the cutting speed and revolutions per minute to consider the *mean* diameter of the cut instead of the outside diameter of the work, and use the value for the mean diameter in the formulas given. When the outside diameter and the depth of the cut are known, the mean diameter equals the outside diameter minus the depth of cut.)

### Cutting Speeds of Milling Cutters

The cutting speeds of milling cutters can be calculated when the diameter of the cutter and the revolutions per minute are given. For instance, the diameter of a cutter is 6 inches and it makes 40 revolutions per minute. To find the cutting speed in feet per minute, first find the circumference of the cutter; thus, $6 \times 3.1416 = 18.8496$, or about 18.8 inches; change this to feet; thus, $18.8 \div 12 = 1.566$ feet. As the cutter makes 40 revolutions per minute, the cutting speed is $40 \times$ the circumference, or $40 \times 1.566 = 62.64$ feet per minute.

If, in the formula just given above, "diam. of work in inches" is substituted by "diameter of cutter," this formula can be used for finding the cutting speed of milling cutters.

If the required cutting speed of a cutter is given and its diameter known, and the number of revolutions at which it should be run is to be found, the formula on page 17 can be used, in this case, also, of course, "diameter of work in inches" being substituted by "diameter of cutter."

### Rules for Calculating Cutting Speeds

1. *To find the number of revolutions per minute when the diameter of the work turned, the hole drilled or bored, or the milling cutter used, in inches, and the cutting speed in feet per minute are given, multiply the diameter by* 3.1416 *and divide the result by* 12. *Then divide the given cutting speed by the quotient thus obtained.*

2. *To find the cutting speed in feet per minute when the diameter of the work to be turned, the hole drilled or bored, or the milling cutter used is given in inches, and the number of revolutions per minute are known, multiply the diameter by* 3.1416 *and divide the result by* 12. *Then multiply the quotient thus obtained by the number of revolutions per minute.*

### Average Cutting Speeds

The cutting speed to use when cutting metals depends primarily upon the kind of tool used and the metal being cut. It is not possible to state exactly what the correct speed would be for all different cases, but the speeds in the table below are given as embodying good average practice when ordinary carbon steel tools are used.

For high-speed steel tools, these speeds may be doubled. In starting high-speed steel drills, a cutting speed of about 50 to 70 feet per minute, for machine steel, 60 to 80 feet per minute for cast iron, and 100 to 140 feet for brass, is recommended. When a few holes have been drilled at these speeds, still higher speeds may be employed.

### Feed of Cutting Tools

The feed of a lathe tool is its sidewise motion (traverse) for each revolution of the work; thus, if the feed is 1/32 inch it means that for each revolution of the work, the lathe carriage and tool move 1/32 inch along the lathe bed, thus cutting a chip 1/32 inch wide.

The feed of a drill in the drill press is the downward motion of the drill per revolution. The feed of a milling cutter is the forward movement of the milling machine table for each revolution of the cutter.

TABLE OF CUTTING SPEEDS IN FEET PER MINUTE

| Machine | Material | | | |
|---|---|---|---|---|
| | Tool Steel Annealed | Wrought Iron and Machine Steel | Cast Iron | Brass |
| Lathe, Planer and Shaper | 18 to 25 | 30 to 40 | 40 to 50 | 80 to 125 |
| Milling Machine | 25 to 35 | 35 to 45 | 40 to 60 | 80 to 120 |
| Drill Press | 20 | 30 | 35 | 60 |

Sometimes the feed is expressed as the distance which the drill or the milling machine table moves forward in one minute. In order to avoid confusion, it is, therefore, always best to state plainly in each case whether feed per revolution or feed per minute is meant.

### Time Required for Turning Work in the Lathe

The most common calculations in which the feed of a lathe tool enters is the time required for turning or boring a given piece of work, when the feed, cutting speed and diameter of work (or the number of revolutions per minute) are known.

Assume that a tool steel arbor, 2 inches in diameter, is to be turned. The length to be turned on the arbor (the length of cut) is 10 inches. The cutting speed is 25 feet per minute and the feed or traverse of the cutting tool is 1/32 inch per revolution. How long a time would it require to take one cut over the surface of the work? We first find the number of revolutions per minute of the work, which equals

$$\frac{25}{(2 \times 3.1416) \div 12} = \frac{25}{0.524} = 47.7.$$

As the tool feeds forward 1/32 inch for each revolution of the work, it is fed forward 47.7 × 1/32 or 1.49 inch in one minute. The time required to traverse the whole length of the work, 10 inches, is obtained by finding how many times 1.49 is contained in 10, or, in other words, by dividing 10 by 1.49. The quotient of this division is 6.71 minutes. It would thus take 7 minutes, approximately, to traverse the work once with the cutting speed and feed given.

Expressed as a formula the calculation takes this form:

$$\text{time required for one cut over the work} = \frac{\text{length of cut}}{\text{rev. per min.} \times \text{feed per revolution}}$$

Expressed as a rule the formula would be:

*To find the time required to take one complete cut over a piece of work in the lathe when the feed per revolution, the total length of cut, and the number of revolutions per minute are given, divide the total length of the cut by the number of revolutions per minute multiplied by the feed per revolution.*

If the cutting speed and diameter of work are given instead of the number of revolutions, first find the revolutions per minute before applying the formula or rule above. (The number of revolutions per minute is found by Rule 1 on page 18.)

When the feed per revolution is known, the feed per minute equals the revolution per minute times the feed per revolution.

## CHAPTER IV

## SCREW THREADS AND TAP DRILLS

The terms pitch and lead of screw threads are often confused. The pitch of a screw thread is the distance from the top of one thread to the top of the next thread, as shown in Fig. 24. No matter whether the screw has a single, double, triple or quadruple thread, the pitch is always the distance from the top of one thread to the top of the next thread. The lead of a screw thread is the distance the nut will move forward on the screw, if it is turned around one full revolution. In the *single-threaded screw, the pitch and lead are equal*, because the nut would move forward the distance from one thread to the next, if turned around once. In a double-threaded screw, however, the nut will move forward two threads, or twice the pitch, so that in a double-threaded screw, the lead equals twice the pitch. In a triple-threaded screw, the lead equals three times the pitch, and so forth. The lead may also be expressed as being the distance from center to center of the *same* thread, after one turn, as indicated in Fig. 25, which shows the pitch and the lead for three screws with Acme threads, the first single-threaded, the second double-threaded, and the last, triple-threaded. In a single-threaded screw, the lead is the distance to the

next thread from the one first considered. In a double-threaded screw there are two threads running side by side around the screw, so that the lead is here the distance to the second thread from the one first considered. In a triple-threaded screw, it is the distance to the third thread, and so forth.

The word pitch is often, though improperly, used in the shop to denote *number of threads per inch.* We hear of screws having 12

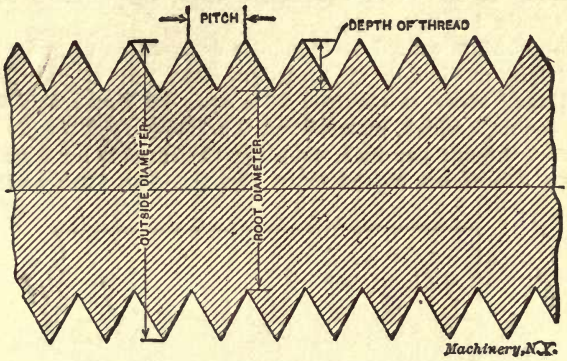



Fig. 24

pitch thread, 16 pitch thread, when 12 threads per inch and 16 threads per inch is what is really meant.

The number of threads per inch is the number of threads counted in the length of one inch, if a scale is held against the side of the screw, and the threads counted as shown in Fig. 26. If there is not a whole number of threads in one inch, count the threads in two or more inches, until the top of one thread comes opposite an inch-mark, and

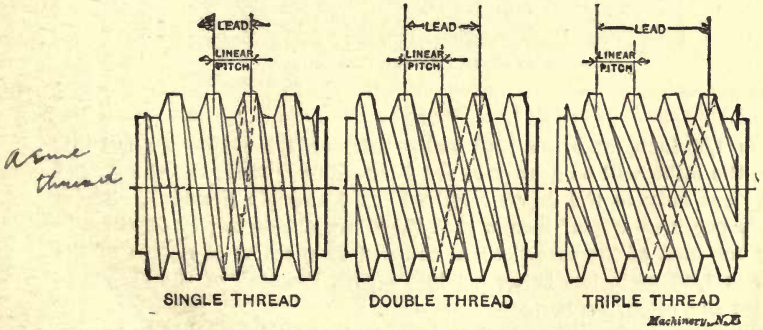



Fig. 25

then divide by the number of inches to find the number of threads in one inch, as shown in Fig. 27.

The number of threads per inch equals 1 divided by the pitch, or expressed as a formula:

$$\text{number of threads per inch} = \frac{1}{\text{pitch}}$$

The pitch of a screw equals 1 divided by the number of threads per inch, or

$$\text{pitch} = \frac{1}{\text{number of threads per inch}}$$

Thus, if the number of threads per inch equals 16, the pitch equals 1/16. If the pitch equals 0.05, the number of threads per inch equals $1 \div 0.05 = 20$. If the pitch equals 2/5 inch, the number of threads per inch equals $1 \div 2/5 = 2\frac{1}{2}$.

Confusion is often caused by indefinite designation of multiple-thread (double, triple, quadruple, etc.) screws. One way of expressing that a double-thread screw is required is to say, for instance: "3 threads per inch double," which means that the screw is cut with 3 *double* threads, or 6 threads per inch, counting the threads by a scale placed alongside of the screw, as shown in Fig. 26. The pitch of this screw

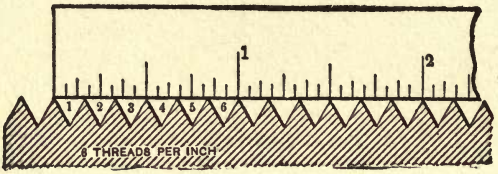



Fig. 26

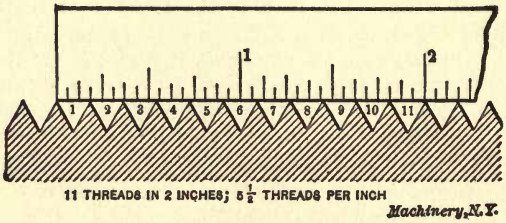



Fig. 27

thus is 1/6 inch, and the lead twice this, or 1/3 inch. To cut this screw, the lathe will be geared to cut 3 threads per inch, but the thread will be cut only to the depth required for 6 threads per inch. "Four threads per inch triple" means that there are 4 times 3, or 12 threads along one inch of the screw, when counted by a scale; the pitch of the screw is 1/12 inch, but being a triple screw, the lead of the thread is 3 times the pitch, or ¼ inch.

The best way of expressing that a multiple-thread screw is to be cut, when the lead and the pitch have been figured, is, for example: "1/4 inch lead, 1/12 inch pitch, triple thread." In the case of single-threaded screws, the number of threads per inch and the form of the thread only are given. The word "single" is not required.

There are three standard threads in common use in American shops. These are shown in Fig. 28, and are the United States standard thread, the sharp V-thread, and the Acme standard thread.

### United States Standard Thread

This thread is the most commonly used thread form for all ordinary screws. The thread is provided with a small flat at the top and at the bottom of the thread, as shown in the illustration to the left in Fig. 28.

The depth of the United States (U.S.) standard thread equals 0.6495 × pitch. The width of the flat of the thread at the bottom and top equals ⅛ × pitch. The root diameter is found by subtracting two times the depth of the thread from the outside diameter of the screw.

[The root diameter of a screw thread is the diameter at the bottom of the thread, as shown in connection with the V-thread in Fig. 24.]

### Standard Sharp V-Thread

This thread has no flat at the top or at the bottom, but the sides of the thread form a sharp point, as shown in the illustration, Fig. 28. The depth of the thread equals 0.866 × pitch. The root diameter is

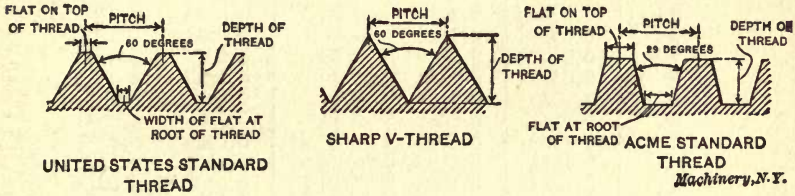



Fig. 28

found by subtracting two times the depth of the thread from the outside diameter of the screw.

### Acme Standard Thread

The form of the Acme standard thread is shown to the right in Fig. 28. The depth of the thread equals ½ × pitch + 0.010 inch. The flat at the top of the thread equals 0.3707 × pitch. The width of the flat at the root of the thread equals 0.3707 × pitch — 0.0052 inch. The root diameter of the thread, of course, is found as before, by subtracting two times the depth of the thread from the outside diameter of the screw.

### Tap Drill Sizes

The tap drills used for drilling holes previous to tapping are usually somewhat larger in diameter than the root diameter of the thread.

The tap drill diameter for ordinary work for the United States standard thread equals the root diameter + (⅛ × pitch).

The tap drill diameter for sharp V-thread equals the root diameter of the thread + (¼ × pitch).

The tap drill diameter for Acme standard thread equals the root diameter + 0.020 inch.

A table of double depths of threads for U. S. and sharp V-threads is given on the following page. The figures in this table opposite any given number of threads per inch are simply subtracted from the outside diameter of the screw, to obtain the root diameter.

*Example:* Find the root diameter of a 1 5/16 inch diameter screw having 8 U. S. threads per inch. The diameter of the screw in decimals is 1.3125. Subtract from this the double depth of the thread, or the so-called "constant," in the table, which is 0.1624, as given opposite 8 threads per inch. The remainder, 1.1501, is the root diameter of the thread.

TABLE OF DOUBLE DEPTH OF SCREW THREADS

| Threads per Inch | U. S. Standard Thread | Standard V-Thread | Threads per Inch | U. S. Standard Thread | Standard V-Thread |
|---|---|---|---|---|---|
| 2 1/4 | 0.5774 | 0.7698 | 18 | 0.0722 | 0.0962 |
| 2 3/8 | 0.5470 | 0.7293 | 20 | 0.0650 | 0.0866 |
| 2 1/2 | 0.5196 | 0.6928 | 22 | 0.0590 | 0.0787 |
| 2 5/8 | 0.4949 | 0.6598 | 24 | 0.0541 | 0.0722 |
| 2 3/4 | 0.4724 | 0.6298 | 26 | 0.0500 | 0.0666 |
| 2 7/8 | 0.4518 | 0.6025 | 28 | 0.0464 | 0.0619 |
| 3 | 0.4330 | 0.5774 | 30 | 0.0433 | 0.0577 |
| 3 1/4 | 0.3997 | 0.5329 | 32 | 0.0406 | 0.0541 |
| 3 1/2 | 0.3712 | 0.4949 | 34 | 0.0382 | 0.0509 |
| 4 | 0.3248 | 0.4330 | 36 | 0.0361 | 0.0481 |
| 4 1/2 | 0.2887 | 0.3849 | 38 | 0.0342 | 0.0456 |
| 5 | 0.2598 | 0.3464 | 40 | 0.0325 | 0.0433 |
| 5 1/2 | 0.2362 | 0.3149 | 42 | 0.0309 | 0.0412 |
| 6 | 0.2165 | 0.2887 | 44 | 0.0295 | 0.0394 |
| 7 | 0.1856 | 0.2474 | 46 | 0.0282 | 0.0377 |
| 8 | 0.1624 | 0.2165 | 48 | 0.0271 | 0.0361 |
| 9 | 0.1443 | 0.1925 | 50 | 0.0260 | 0.0346 |
| 10 | 0.1299 | 0.1732 | 52 | 0.0250 | 0.0333 |
| 11 | 0.1181 | 0.1575 | 56 | 0.0232 | 0.0309 |
| 12 | 0.1083 | 0.1443 | 60 | 0.0217 | 0.0289 |
| 13 | 0.0999 | 0.1332 | 64 | 0.0203 | 0.0271 |
| 14 | 0.0928 | 0.1237 | 68 | 0.0191 | 0.0255 |
| 15 | 0.0866 | 0.1155 | 72 | 0.0180 | 0.0241 |
| 16 | 0.0812 | 0.1083 | 80 | 0.0162 | 0.0217 |

These constants are subtracted from the outside diameter of the tap or screw; the result is the root diameter of the thread

When the table of double depth of threads is used for multiple-thread screws, it should be noted that the number of threads per inch as measured along the screw as shown in Fig. 26, should be taken. Thus, for instance, to find the root diameter of a screw having 6 threads per inch double, the figures opposite 12 threads (6 double) should be used.

## CHAPTER V

## TRAINS OF GEARS

Suppose that two shafts *A* and *B*, as shown in Fig. 29, are to be connected by gearing so that shaft *A* makes one revolution while shaft *B* makes three. To obtain this result, the gear on *A* must have three times as many teeth as the gear on *B*. Assume that we have 90 teeth in the gear on *A*; the gear on *B* must then have only 30 teeth. Each

time the small gear on *B* turns around one complete revolution, it engages 30 teeth in the gear on shaft *A*. It therefore must turn around three full revolutions in order to engage all the 90 teeth in the larger gear, or, in other words, the smaller gear revolves three times in order to revolve the gear on *A* once. The *ratio* of this gearing is 3 to 1. If one gear revolves three times while the mating gear revolves four times, the ratio of the gearing would be 3 to 4. The ratio of gearing expresses the relation between the number of times which one gear revolves and the number of times the mating gear revolves in the same time.

### Effect of Idlers

Assume that the shafts *C* and *D* in Fig. 30 are required to run in a ratio of 5 to 1, that is, shaft *C* is to revolve five times while shaft *D*

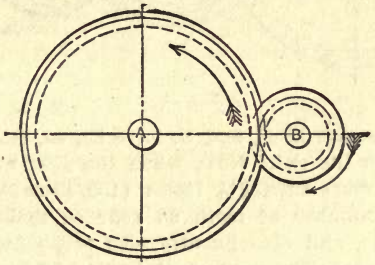



Fig. 29

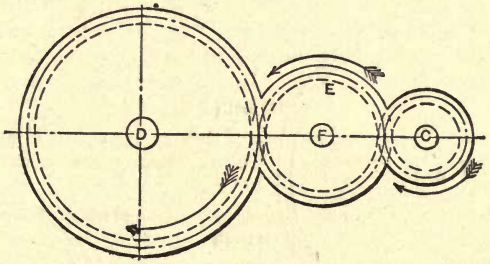



Fig. 30

revolves once. If a 20-tooth gear is placed on shaft *C*, the gear on shaft *D* must have five times as many teeth, or 100 teeth; then it will revolve but once when the gear on *C* revolves five times. Assume that we put gears with the number of teeth mentioned on the shafts. The distance between the shafts may now be such that the gears will not mesh or engage. An intermediate gear *E* mounted on a stud *F* may then be placed so that it meshes with both the gear on *C* and the gear on *D*. The intermediate gear simply transmits motion from the gear on *C* to the gear on *D*, but has no influence on the ratio of speed of the shafts *C* and *D*. When the intermediate gear is in place, the gear on *C* still revolves five times while the gear on *D* revolves once.

If we place a number of intermediate gears, *E*, *F*, and *G*, in the train, as in Fig. 32, the result would still be the same, the gear on *C*

would turn 5 times while the gear on *D* turned once, as long as the number of teeth in the gear on *D* is 5 times the number of teeth in the gear on *C*.

In order to prove this, let us assume that in Fig. 32, the gear on stud *C* has 20 teeth, and the gear on stud *D*, 100 teeth, so that consequently the stud *C* makes 5 revolutions, while stud *D* makes one.

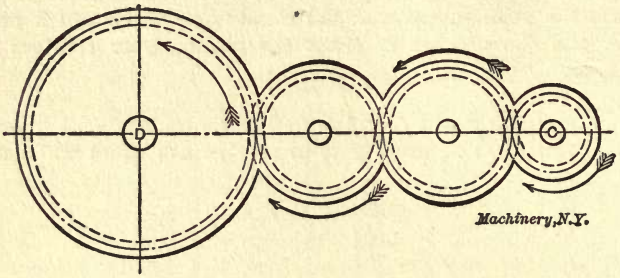



Fig. 31

The intermediate gears, *E*, *F*, and *G*, have 50, 40, and 40 teeth, respectively, as shown in the cut. Now, when the gear on *D* turns around once, the gear *G* must turn 2½ times (100/40 = 2½). The gear *F*, having the same number of teeth as gear *G*, makes one revolution while *G* makes one, and consequently also turns 2½ times while the gear on *D* turns once. The gear on *E*, having 50 teeth, turns 4/5 of a

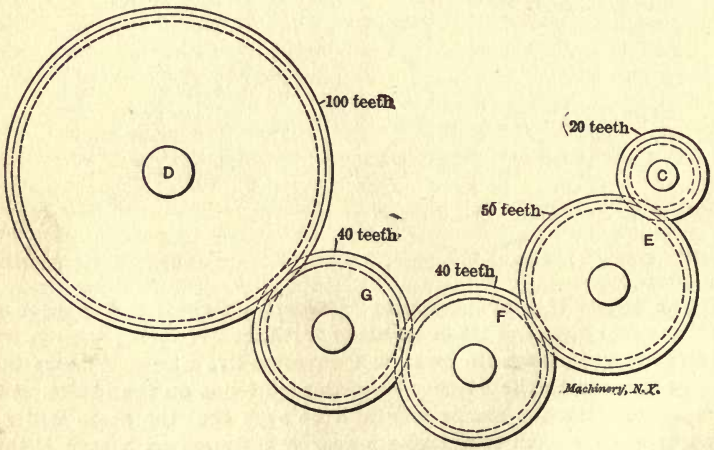



Fig. 32

revolution while gear *F* revolves once (40/50 = 4/5), and consequently, while *F* makes 2 1/2 revolutions, gear *E* makes 2 1/2 × 4/5 = 5/2 × 4/5 = 2 revolutions. Thus *E* turns twice while the gear on stud *D* revolves once. Finally, the gear on *C* turns 2 1/2 times to each revolution of gear *E* (50/20 = 2 1/2), or 5 times to 2 revolutions of *E*. But 2 revolutions of *E* correspond, as we have seen, to one revolution of

the gear on stud *D*; consequently, the gear on stud *C* makes 5 revolutions to one of the gear on stud *D*, which, as we previously said, is also the case if these two gears had been connected directly without any intermediate gearing.

The intermediate gears, however, affect the direction in which the gear on *D* revolves. In Fig. 29, when the gear on *B* revolves in a right-hand direction (in the same direction as the hands of a watch), the gear on *A*, which is driven by it, will move in a left-hand direction (in a direction opposite to that of the hands of a watch. Thus when there is no intermediate gear, the driving gear and the driven gear revolve in opposite directions. In Fig. 30, again, the gear on *C* moves in a right-hand direction, the gear on *F* in a left-hand direction, and the gear on *D* in a right-hand direction, so that in this case both the driver on *C* and the driven gear on *D* move in the same direction.

If there be two idlers, as shown in Fig. 31, the speed ratio between the shafts *C* and *D* still remains the same as before, but it will be seen from the arrows indicating the directions in which the different gears revolve, that in this case, the driver on *C* and the driven gear on *D* move in opposite directions. The use of two idlers, therefore, makes the driven gear run in the same direction as if there was no idler between the gears on *C* and *D*. If there were three idlers the gears on *C* and *D* would run in the same direction, and if there were four idlers, they would run in opposite directions, and so on.

### Gears Required for a Given Speed Ratio

If we have two gears *A* and *B*, as shown in Fig. 33, and the ratio of the speed of gear *A* to the speed of gear *B* and the number of teeth in one of the gears are given, the number of teeth required in the other gear can be determined; and if the ratio only is given, the number of teeth in both the gears can be found.

Assume that the ratio of the speed of gear *A* to gear *B* is 1 to 4. This means that gear *A* revolves once while gear *B* revolves four times. If there be 80 teeth in gear *A*, gear *B* must have one-fourth of this number, or 20 teeth. Had the speed ratio been 2 to 5, then if gear *A* had 50 teeth, gear *B* would have $\frac{2}{5} \times 50 = 20$ teeth. From this we may formulate the following rule:

*If the speed ratio of the driving gear to the driven gear and the number of teeth in the driving gear are given, the number of teeth in the driven gear may be found by multiplying the number of teeth in the driving gear by the speed ratio, written as a fraction.*

Assume, for instance, that the speed ratio of gear *A* to gear *B* is 3 to 5, and that the number of teeth in gear *A* is 60. Writing the speed ratio as a fraction gives us 3/5, and this multiplied by 60 gives us 36, which is the number of teeth in the gear *B*.

Note that when the speed ratio of gear *A* to gear *B* is given, we multiply the number of teeth in gear *A* with the speed ratio written as a fraction, to get the number of teeth in gear *B*. But if the number of teeth in gear *B* is given, and the number of teeth in gear *A* is to

be found, the number of teeth in gear *B* should be multiplied by the *inverted* speed ratio. (To invert a fraction means to turn it upside down, so that the numerator becomes the denominator, and the denominator becomes the numerator.) If the speed ratio of gear *A* to gear *B* is 2 to 3, and the number of teeth in gear *B* is 34, then the number of teeth in gear *A* is found by multiplying 34 by the inverted ratio; thus:

$$34 \times \frac{3}{?} = \frac{102}{2} = 51.$$

It is helpful to remember when doing calculations of this kind that the larger gear, which, of course, is the gear with the greater number of teeth, is always the gear which will make the fewer number of revolutions. Keeping this in mind will prevent mistakes.

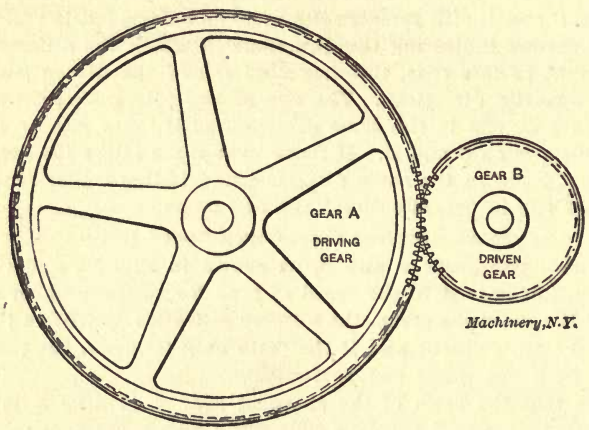



Fig. 33

If the speed ratio of two shafts is given, and the numbers of teeth for two gears which will transmit motion between the shafts at the given speed ratio is to be found, write the speed ratio in the form of a fraction and multiply the numerator and the denominator by the same number until a new fraction is obtained, having numerator and denominator expressing suitable numbers of teeth for the gears.

If the given speed ratio be 4 to 7, and it is required to find two gears which will transmit motion between the two shafts at this ratio, write the ratio as a fraction (4/7), and multiply numerator and denominator by the *same* number, thus:

$$\frac{4}{7} = \frac{4 \times 8}{7 \times 8} = \frac{32}{56}.$$

By multiplying 4 and 7 by 8 we obtain two gears with 32 and 56 teeth, which will transmit the motion from one shaft to another at the required ratio. The larger gear, with 56 teeth is placed on the shaft with the lowest number of revolutions.

### Finding the Number of Revolutions per Minute

If the numbers of teeth in the two gears and the number of revolutions per minute of one shaft are known, and it is required to find the number of revolutions of the other shaft, the following rule is used:

*The number of revolutions of one shaft multiplied by the number of teeth of the gear on the same shaft, divided by the number of teeth in the gear on the second shaft, gives the number of revolutions of the second shaft.*

Written as a formula this rule would be:

$$\frac{\text{rev. of first shaft} \times \text{teeth in gear on first shaft}}{\text{teeth in gear on second shaft}} = \text{rev. of second shaft.}$$

If the speed ratio is given instead of the numbers of teeth, the numbers of teeth may first be found by the rules previously given.

### Finding the Speed Ratio

The speed ratio can be found if either the numbers of teeth in both of the gears, or the numbers of revolutions per minute of both of the gears, are given.

If the numbers of revolutions of two gears *A* and *B* are given, the ratio of the speed of gear *A* to gear *B* is found by placing the number of revolutions of gear *A* as the numerator and the revolutions of gear *B* as the denominator of a fraction, and reducing this fraction to its lowest terms.* If gear *A* makes 34 revolutions, and gear *B*, 85 revolutions, the speed ratio of gear *A* to gear $B = \frac{34}{85} = \frac{2}{5}$ or, as it is commonly expressed, 2 to 5.

If the numbers of teeth in the gears *A* and *B* are given, the speed ratio of gear *A* to gear *B* is found by writing the number of teeth of gear *B* as the numerator, and of gear *A* as the denominator of a fraction, and reducing the fraction to its lowest terms. If the number of teeth in gear *A* is 60, and in gear *B*, 48, the ratio of speed of gear *A* to gear $B = \frac{48}{60} = \frac{4}{5}$, or 4 to 5.

### Compound Gearing

The simplest and most common case of *compound* gearing consists of four gears mounted as shown in Fig. 34. The gear *A* is the driver and meshes with gear *B*, which is keyed to the same shaft as gear *C*. Thus, when gear *B* is driven by gear *A*, gear *C* will revolve at the same rate of speed as gear *B*, and will drive gear *D*; the motion of gear *A* is thus transmitted to gear *D*. The two gears *B* and *C* which serve to transmit the motion are called *intermediate* gears. The gears *A* and *C* are the *driving* gears, and *B* and *D* the *driven* gears.

If it is required to find the revolutions of the driven gear *D* when the number of revolutions of gear *A* and the numbers of teeth in all the gears are known, the following rule is used:

* See MACHINERY'S Jig Sheet No. 6A.

*The revolutions per minute of the driven gear equals the revolutions per minute of the driving gear, times a fraction, the numerator of which is made up of the product of the numbers of teeth in the driving gears, and the denominator of the product of the numbers of teeth in the driven gears.*

This rule can be written as a formula as below:

$$\text{rev. per min. of driven gear} = \text{rev. per min. of driving gear} \times \frac{\text{product of teeth in driving gears}}{\text{product of teeth in driven gears}}$$

This formula can be used whether there be one or more sets of intermediate gears.

Assume that gear *A* in Fig. 34 has 40 teeth, gear *B*, 24 teeth, gear *C*, 50 teeth, and gear *D*, 25 teeth. Then if gear *A* makes 30 revolutions

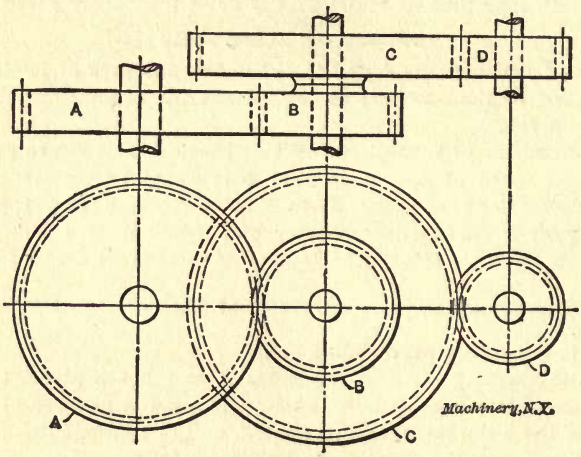



Fig. 34

per minute, how many revolutions does gear *D* make? Using the formula just given we have:

$$\text{rev. per min.} = 30 \times \frac{40 \times 50}{24 \times 25} = 100.$$

The revolutions per minute made by gear *B* may be found from the same formula by leaving out the numbers of teeth of gears *C* and *D*, thus:

$$\text{rev. per min.} = 30 \times \frac{40}{24} = 50.$$

### Finding the Number of Teeth in Gears to Transmit Motion at a Given Ratio

If the numbers of revolutions of the driving gear *A* and the driven gear *D* are given, the numbers of teeth required in the four gears of a compound gearing that will transmit motion at the required ratio, can be found.

Assume that gear *A*, Fig. 34, makes 36 revolutions per minute and that it is required that gear *D* should make 56 revolutions. The speed ratio is then $\frac{36}{56} = \frac{9}{14}$. (See page 29.)

*To find the gears required, write the ratio of the speed of the driving gear to the driven gear as a fraction, divide the numerator and denominator in two factors, and multiply each "pair" of factors by the same number until gears with suitable numbers of teeth are found.* (One factor in the numerator and one in the denominator make "one pair.") In this example

$$\frac{9}{14} = \frac{3 \times 3}{2 \times 7} = \frac{(3 \times 20) \times (3 \times 10)}{(2 \times 20) \times (7 \times 10)} = \frac{60 \times 30}{40 \times 70}$$

The gears in the numerator, with 60 and 30 teeth, are the driven gears (gears *B* and *D*, Fig. 34), and the gears in the denominator, with 40 and 70 teeth, are the driving gears (gears *A* and *C*, Fig. 34).

The calculation may be expressed in a formula as follows:

$$\text{ratio of speed of the first driving gear to the last driven gear} = \frac{\text{product of teeth in driven gears}}{\text{product of teeth in driving gears}}$$

## CHAPTER VI

## LATHE CHANGE GEARING

While the principles and rules governing the calculation of change gears are very simple, they, of course, presuppose some fundamental knowledge of the use of common fractions. If such knowledge is at hand, the subject of figuring change gears, if once thoroughly understood, can hardly ever be forgotten. It should be impressed upon the minds of all who have found difficulties with this subject that the matter is seldom approached in a logical manner, and is usually grasped by the memory rather than by the intellect.

When cutting threads in the lathe, the lathe carriage is moved along the bed by means of the lead-screw a certain distance while the work revolves a certain number of times. If the work revolves 12 times while the carriage moves one inch along the bed of the lathe, 12 threads per inch will be cut on the work.

Change gears are used for transmitting the motion from the spindle (which revolves the work) to the lead-screw (which causes the carriage to move along the bed). The number of times that the spindle will revolve while the carriage moves one inch along the lathe bed is determined by the ratio of the change gears. By employing different ratios of change gearing, therefore, different numbers of threads per inch can be cut.

The change gearing may be either *simple* or *compound.* Simple gearing is shown in the accompanying illustration, Fig. 35. When simple gearing is used it is always necessary to use an idler between the gear on the spindle stud and the gear on the lead-screw. As already explained, this idler has no influence on the ratio of the gearing, and can have any number of teeth. Compound change gearing is shown in Fig. 36.

### Finding the Lathe Screw Constant

In order to be able to calculate change gears for the lathe, it is necessary first to find the "lathe screw constant." This constant is always the same for each particular lathe, but it may be different for lathes of different sizes or makes.

*To find the screw constant of a lathe, place gears with an equal number of teeth on the spindle stud and the lead-screw. Then cut a thread on a piece of work in the lathe. The number of threads per inch that*

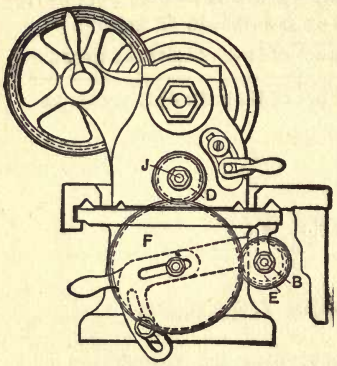



Fig. 35

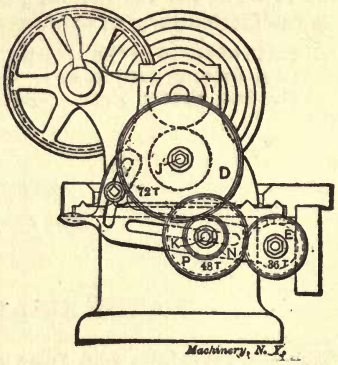



Fig. 36

*will be cut on the work when gears with equal numbers of teeth are placed as directed is called the "screw constant" of the lathe.*

For example, put gears with 48 teeth on the spindle stud and on the lead-screw, and any convenient gear on the intermediate stud. Then cut a thread on a piece between the centers. If the number of threads per inch when counted as shown on page 22 is found to be 8, the screw constant of this lathe is said to be 8.

### To Find the Change Gears for Simple Gearing

When the lathe screw constant has been found, the number of teeth to be used in the change gears for cutting any number of threads within the capacity of the lathe can be determined as follows:

*Place the lathe screw constant as the numerator and the number of threads per inch to be cut as the denominator of a fraction and multiply the numerator and denominator by the same number until a new fraction results where the numerator and denominator represent suitable numbers of teeth for the change gears.* In the new fraction the numerator gives the number of teeth in the gear on the spindle stud, and the

denominator the number of teeth in the gear on the lead-screw. This rule can be more easily remembered if written as a formula:

$$\frac{\text{lathe screw constant}}{\text{threads per inch to be cut}} = \frac{\text{teeth in gear on spindle stud}}{\text{teeth in gear on lead-screw}}$$

Assume that 10 threads per inch are to be cut in a lathe where we have found that the lathe screw constant is 6. Also assume that the numbers of teeth in the available change gears of this lathe are 24, 28, 32, 36, 40, etc., increasing by 4 up to 100. By substituting the figures given, in the formula above, and carrying out the calculation, we have:

$$\frac{6}{10} = \frac{6 \times 4}{10 \times 4} = \frac{24}{40}.$$

By multiplying both numerator and denominator by 4 we obtain two available gears with 24 and 40 teeth, respectively. The 24-tooth gear goes on the spindle stud, and the 40-tooth gear on the lead-screw. It will be seen that if we had multiplied 6 and 10 by 5, we would have obtained 30 and 50 teeth, which gears are not available in our set of gears with this lathe. Until getting accustomed to figuring of this kind, one can find, by trial only, the correct number by which to multiply the numerator and denominator. The trials must be kept up until both gears have such a number of teeth that they are to be found in the set of change gears accompanying the lathe.

Assume that it is required to cut 11½ threads per inch in the same lathe having the same set of change gears. Then

$$\frac{6}{11\frac{1}{2}} = \frac{6 \times 8}{11\frac{1}{2} \times 8} = \frac{48}{92}.$$

It will be found that multiplying by any other number than 8 would not, in this case, give numbers of teeth that could be found in the gears with the lathe. [In order to prevent mistakes, be sure to note that the lathe screw constant differs for different makes and sizes of lathes and must be determined for each particular lathe.]

### Compound Gearing

Sometimes it is not possible to obtain gears that will give the required ratio for the thread to be cut in a simple train, and then compound gearing must be employed. The method for finding the number of teeth in the gears in compound gearing is exactly the same as for simple gearing, except that we divide both numerator and denominator of the fraction giving the ratio of screw constant to threads per inch to be cut, into two factors, and then multiply each "pair" of factors by the same number, in order to obtain the change gears. (One factor in the numerator and one in the denominator make one pair.)

Assume that the lathe screw constant is 6, that the numbers of teeth in the available gears are 30, 35, 40, 45, 50, 55, etc., increasing by 5 up to 100. Assume that it is required to cut 24 threads per inch. We have then,

$$\frac{6}{24} = \text{ratio}.$$

By dividing numerator and denominator of the ratio into two factors and multiplying each pair of factors by the same number, as shown below, we find the gears:

$$\frac{6}{24} = \frac{2 \times 3}{4 \times 6} = \frac{(2 \times 20) \times (3 \times 10)}{(4 \times 20) \times (6 \times 10)} = \frac{40 \times 30}{80 \times 60}.$$

The four numbers in the last fraction give the numbers of teeth in the gears which should be used. The gears in the numerator, with 40 and 30 teeth, are the driving gears, and those in the denominator, with 80 and 60 teeth, are the driven gears. Driving gears are, of course, the gear *D*, Fig. 36, on the spindle stud, and the gear *P* on the intermediate stud *K*, meshing with the lead-screw gear. Driven gears are the lead-screw gear, *E*, and the gear *N* on the intermediate stud meshing with the spindle stud gear. Either of the driving gears may be placed on the spindle stud, and either of the driven on the lead-screw.

Assume that 1¾ threads per inch are to be cut in a lathe with a screw constant 6, and that the gears available have 24, 28, 32, 36, 40 teeth, etc., increasing by 4 up to 100. Proceeding as before we have:

$$\frac{6}{1\frac{3}{4}} = \frac{2 \times 3}{1 \times 1\frac{3}{4}} = \frac{(2 \times 36) \times (3 \times 16)}{(1 \times 36) \times (1\frac{3}{4} \times 16)} = \frac{72 \times 48}{36 \times 28}.$$

This is the case directly illustrated in Fig. 36. The gear with 72 teeth is placed on the spindle stud *J*, the one with 48 on the intermediate stud *K*, meshing with the lead-screw gear. These two gears (72- and 48-teeth) are the *driving* gears. The gears with 36 and 28 teeth are placed on the lead-screw, and on the intermediate stud, as shown, and are the *driven* gears.

The rule for compound change gears, given as a formula, is as follows:

$$\frac{\text{lathe screw constant}}{\text{threads per inch to be cut}} = \frac{\text{product of teeth in driving gears}}{\text{product of teeth in driven gears}}$$

### Fractional Threads

Sometimes the lead of a thread is given as a fraction of an inch instead of stating the number of threads per inch. For instance, a thread may be required to be cut, having ⅜ inch lead. In this case the expression "⅜ inch lead" should first be transformed to "number of threads per inch," after which we can proceed to find the change gears as explained on the previous pages. How to find the number of threads per inch when the lead is given is explained in Chapter IV. The number of threads (the thread being single) equals:

$$\text{number of threads per inch} = \frac{1}{\frac{3}{8}} = 1 \div \frac{3}{8} = \frac{8}{3} = 2\frac{2}{3}.$$

To find the change gears to cut 2 2/3 threads per inch in a lathe having a screw constant 8 and change gears running from 24 to 100 teeth, increasing by 4, proceed as below:

$$\frac{8}{2\ 2/3} = \frac{2 \times 4}{1 \times 2\ 2/3} = \frac{(2 \times 36) \times (4 \times 24)}{(1 \times 36) \times (2\ 2/3 \times 24)} = \frac{72 \times 96}{36 \times 64}.$$

## CHAPTER VII

## SPEED OF PULLEYS

The principle applied to gearing in regard to the ratio between the speeds of two shafts, may be directly applied to the question of sizes of pulleys, with the only difference that we here deal with the number of inches to the diameter of the pulley instead of the number of teeth in the gear.

Assume that a shaft is required to make 300 revolutions per minute, and that it is driven from a line-shaft making 180 revolutions per minute, as shown in the illustration below. The pulley on the line-shaft is in place, and is 15 inches in diameter. What diameter should the pulley on the shaft making 300 revolutions per minute be made? As the belt on the two pulleys runs at the same speed as the periphery (circumference) of either of the pulleys, it is clear that the peri-

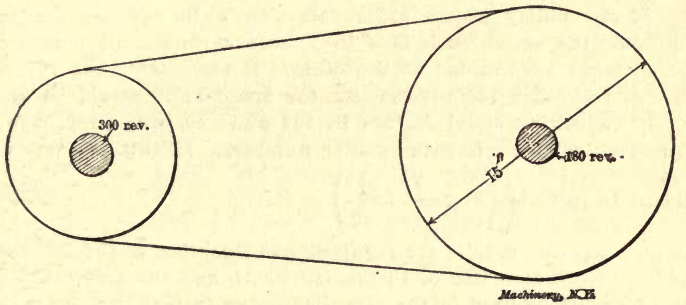



Fig. 37

pheries of both pulleys run at the same speed, providing there is no slippage between the belt and the pulleys. The pulley running a smaller number of revolutions must, of course, be larger in order that its periphery may run at the same speed as the periphery of the pulley making a greater number of revolutions. The circumference of a circle (and, therefore, also the circumference of a pulley) equals the diameter $\times$ 3.1416. Therefore, the circumference of the pulley making 180 revolutions and having a diameter of 15 inches, passes, in one minute, through a distance equal to 180 times its circumference, or $180 \times 15 \times 3.1416$.

The circumference of the pulley making 300 revolutions must pass through the same distance in one minute; therefore, for *each* revolution this pulley must pass through the distance $180 \times 15 \times 3.1416$ divided by 300. This, then, would equal the circumference of the smaller pulley; but the circumference also equals the *diameter* $\times$ 3.1416. We can therefore write

$$\frac{180 \times 15 \times 3.1416}{300} = \text{diameter of smaller pulley} \times 3.1416$$

As 3.1416 enters as a factor on both sides of the equals sign, it can be cancelled. Then we have:

$$\frac{180 \times 15}{300} = \text{diameter of smaller pulley.}$$

From this we can formulate the following rule for the relation between the sizes of pulleys and the number of revolutions of two shafts:

*The number of revolutions of one shaft multiplied by the diameter of the pulley on the same shaft divided by the number of revolutions of the second shaft, gives the diameter of the pulley on the second shaft.*

We can write this rule in the form of a formula, as follows:

$$\text{diameter of pulley on second shaft in inches} = \frac{\text{number of revolutions of first shaft} \times \text{diameter of pulley on first shaft in inches}}{\text{number of revolutions of second shaft}}$$

If one pulley makes 200 revolutions while another pulley makes 100 revolutions, we say that the *speed ratio* between the two pulleys is 2 to 1. If one pulley makes 200 revolutions while another makes 50 revolutions, the speed ratio is 4 to 1, because one shaft makes four times as many revolutions as the other. If one shaft runs 200 revolutions and another 140 revolutions, the speed ratio would be 200 to 140. By cancelling equal factors in 200 and 140, we can reduce the ratio so as to express it with smaller numbers. In this case the ratio would be 10 to 7. $\left(\frac{200}{140} = \frac{20}{14} = \frac{10}{7}\right)$

[If very accurate results are required, one thickness of the belt should be added to the diameter of the pulley itself, and the dimension thus obtained should be used in the formulas above instead of the diameter of the pulley rim. For instance, if the pulley is 5 inches in diameter and the belt ⅛ inch thick, the diameter to be used in the formulas should be 5⅛ inches. The results obtained in this manner will be very accurate provided there is no slipping of the belt on either of the pulleys. For ordinary practical purposes, however, it is usual to figure with the diameter of the pulley rim, taking no account of the thickness of the belt.]

### Finding the Number of Revolutions of a Shaft

If we know the diameters of the pulleys and the number of revolutions per minute of one shaft, and want to find the number of revolutions of the other shaft, we use the following rule:

*The number of revolutions on one shaft multiplied by the diameter of the pulley on the same shaft, divided by the diameter of the pulley on the second shaft, gives the number of revolutions of the second shaft.*

This rule can be written as a formula as follows:

$$\text{number of revolutions of second shaft} = \frac{\text{number of revolutions of first shaft} \times \text{diameter of pulley on first shaft}}{\text{diameter of pulley on second shaft}}$$

**Practical Applications**

*Example* 1. A line-shaft for some grinding machines is required to run at 320 revolutions per minute and is to be driven from a main line-shaft running at 200 revolutions per minute. The pulley on the main line shaft is already in place and is 24 inches in diameter. What diameter ought the pulley of the grinding machine line-shaft to be? If we apply our first rule or formula we have directly:

$$\frac{200 \times 24}{320} = 15$$

The diameter of the pulley on the grinding machine line-shaft therefore should be 15 inches.

*Example* 2. The pulley on a geared-head lathe is 16 inches in diameter. The driving pulley on the line-shaft is 34 inches in diameter, and the line-shaft makes 120 revolutions per minute. How many revolutions does the 16-inch pulley on the lathe make?

If we apply the second rule or formula given we have directly:

$$\frac{120 \times 34}{16} = 255$$

The 16-inch pulley consequently makes 255 revolutions per minute.

*Example* 3. The largest step of a cone-pulley on the countershaft of a machine is 12 inches in diameter. The smallest step is 6 inches. The largest step on the cone-pulley on the machine is 10 inches, the smallest, 4. If the countershaft runs at 300 revolutions per minute, what are the highest and lowest speeds of the spindle on which the cone-pulley on the machine is mounted?

The largest step of each respective pulley runs with the smallest step of the other. We can, therefore, proceed as if we had two sets of pulleys, one set 12 and 4, and one, 6 and 10 inches in diameter, and by using the second rule or formula given we have:

$$\frac{300 \times 12}{4} = 900 \quad \text{and} \quad \frac{300 \times 6}{10} = 180$$

The highest speed is therefore 900 revolutions per minute and the lowest 180 revolutions.

## CHAPTER VIII

## CHANGE GEARS FOR MILLING SPIRALS

The method for the figuring of change gears for cutting spirals on the milling machine, is, in principle, exactly the same as that used for figuring change gears for the lathe (see Chapter VI), but it will be necessary to shortly refer to the construction of the mechanism for connecting the index head spindle and the feed-screw to make perfectly clear the fundamental ideas governing the selection of change gears.

In Fig. 38 is shown an end view of an index head for a milling machine, placed on the top of the milling machine table. At *A* is

shown the end of the table feed-screw, and *B* is a gear placed on this feed-screw. This gear is commonly called the feed-screw gear, and it imparts motion, through an intermediate gear *H*, to the gear *C* which is placed on the stud *D;* from this stud, in turn, motion is imparted by gearing to the worm of the index head and from the worm to the worm-wheel mounted on the index head spindle. Thus, when connected by gearing in this manner, the index head spindle may be rotated from the feed-screw. The gear *C* on the stud *D* is called the "worm gear"; this worm gear should not be confused with the worm-wheel which is permanently attached to the index head spindle.

In Fig. 38 is shown a case of simple gearing, while in Fig. 39 the gears are compounded. In this case *B* still represents the feed-screw gear, while *E* is the gear on the intermediate stud which meshes with *B*, and *F* is the second gear on the same intermediate stud, meshing with gear *C*. The object of the calculation is to find the numbers of teeth in gears *B* and *C* used in a simple train, as in Fig. 38; or in the gears *B*, *E*, *F* and *C* as used in a compound train of gears, as shown in Fig. 39.

### The Lead of a Milling Machine

If gears with an equal number of teeth are placed on the feed-screw *A* and the stud *D* in Fig. 38. then the *lead of the milling machine* is the distance the table will travel while the index spindle makes one complete revolution. This distance is a constant used in figuring the change gears, and may vary for different milling machines.

The lead of a helix or spiral is the distance, measured along the axis of the work, in which the spiral makes one full turn around the work. The lead of the milling machine may, therefore, also be expressed as the lead of the spiral that will be cut when gears with an equal number of teeth are placed on studs *A* and *D*, and an idler of suitable size interposed between the gears.

*To find the lead of a milling machine, place equal gears on stud D, and on feed-screw A, Fig.* 38, *and multiply the number of revolutions made by the feed-screw to produce one revolution of the index head spindle, by the lead of the thread on the feed-screw.*

We can express the rule given as a formula:

$$\text{lead of milling machine} = \text{rev. of feed-screw for one revolution of index spindle with equal gears} \times \text{lead of feed-screw}$$

Assume that it is necessary to make 40 revolutions of the feed-screw to turn the index head spindle one complete revolution, when the gears *B* and *C*, Fig. 38, are equal, and that the lead of the thread on the feed-screw of the milling machine is ¼ inch; then the lead of the machine equals

$$40 \times \tfrac{1}{4} \text{ inch} = 10 \text{ inches.}$$

### Change Gears for Cutting Spirals

As has already been stated, the lead of the machine means the distance which the table of the milling machine moves forward in order to turn the work placed on the index head spindle one complete revo-

lution when change gears with an equal number of teeth are used. If then, for instance, a spiral is to be cut, the lead of which is twice as long as the lead of the machine, change gears of such a ratio must be used that the index head spindle will turn only one-half a revolution while the table moves forward a distance equal to the lead of the machine.

Assume that we want to cut a spiral having a lead of 20 inches, that is, making one complete turn in a length of 20 inches, and that the lead of the milling machine is 10 inches. Then the ratio between the

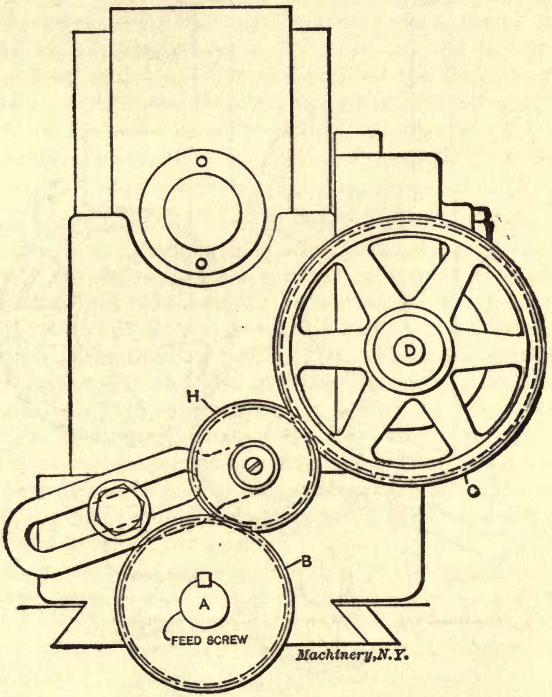



Fig. 38

speeds of the feed-screw and of stud *D* must be 2 to 1, which means that the feed-screw, which is required to turn twice while stud *D* turns once, must have a gear that has only one-half the number of teeth of the gear placed on stud *D*. (See Chapter V.) If the lead of the machine is 10 inches and the lead of the spiral required to be cut on a piece of work is 30 inches, then the ratio between the speed of the gears would be 3 to 1, which is the same as the ratio between the lead of the spiral to be cut to the lead of the machine. (30 to 10 = 3 to 1, or as it is commonly written 30 : 10 = 3 : 1.)

The rule for finding the change gears can be expressed by a simple formula:

$$\frac{\text{lead of spiral to be cut}}{\text{lead of milling machine}} = \frac{\text{number of teeth in gear on worm stud } (D, \text{Fig. 38})}{\text{number of teeth in gear on feed-screw}}$$

Expressed in words this formula would read:

*To find the change gears to be used in a simple train of gearing when cutting spirals in the milling machine, place the lead of the spiral as the numerator and the lead of the milling machine as the denominator of a fraction, and multiply the numerator and denominator by*

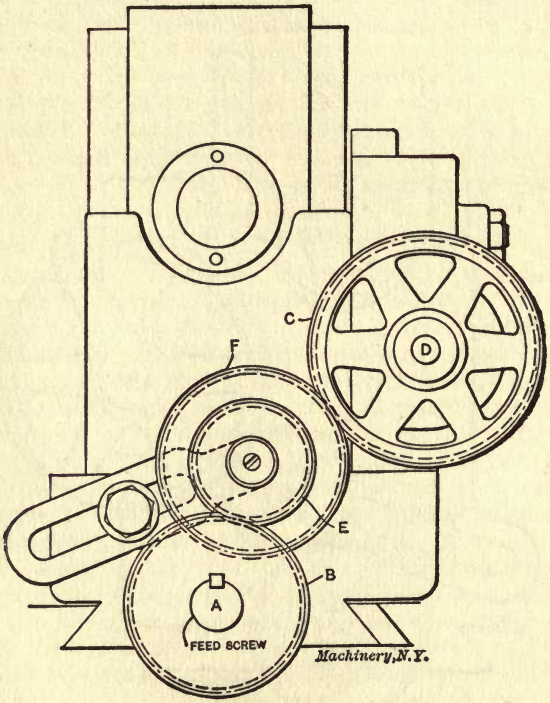



Fig. 39

*the same number until a new fraction is obtained in which the numerator and denominator give suitable numbers of teeth for the gears.*

As an example of this rule, take the case of a milling machine in which there are four threads per inch on the feed-screw and where 40 revolutions of the feed-screw are necessary to make the index spindle turn one complete revolution when gears *B* and *C*, Fig. 38, are equal. It is required on this machine to cut a spiral, the lead of which is 12 inches.

We first find the lead of the machine. As the feed-screw is single and has 4 threads per inch, the lead of the screw thread is ¼ inch (see Chapter IV), which multiplied by 40 is

$$40 \times \tfrac{1}{4} \text{ inch} = 10 \text{ inches} = \text{lead of machine.}$$

To find the change gears, place the lead of the required spiral as the numerator of a fraction and the lead of the machine as the denominator, and multiply both numerator and denominator by the same number until a new fraction is obtained in which the numerator and denominator express suitable numbers of teeth. Following this rule, then,

$$\frac{12}{10} = \frac{12 \times 4}{10 \times 4} = \frac{48}{40}$$

The gear with 48 teeth is placed on stud *D* which, of course, is required to revolve slower than the lead-screw, in order to cut a spiral which is 12 inches, when the spiral cut with equal gears is only 10 inches. The gear having 40 teeth is placed on the feed-screw. An intermediate gear is put between the gear on the feed-screw and the gear on stud *D;* the number of teeth in this intermediate gear has no influence on the speed ratio of feed-screw *A* and stud *D*, but simply serves to transmit motion from one gear to the other. (See Chapter V.)

### Gears for Compound Gearing

If it is not possible to find a set of two gears that will transmit the required motion, it is necessary to use compound gearing. In this case the manner in which the gears are found is exactly the same as the method used for compound gearing in the lathe. The lead of the required spiral is placed as the numerator and the lead of the milling machine as the denominator of a fraction. Then the numerator and denominator are divided into two factors each, and then each "pair" of factors (one factor in the numerator and one in the denominator making one "pair") is multiplied by the same number until suitable numbers of teeth for the change gears are obtained.

As an example, assume that the lead of a machine is 10 inches, and that a spiral having a 48-inch lead is to be cut. Following the method explained we then have.

$$\frac{48}{10} = \frac{6 \times 8}{2 \times 5} = \frac{(6 \times 12) \times (8 \times 8)}{(2 \times 12) \times (5 \times 8)} = \frac{72 \times 64}{24 \times 40}$$

The gear having 72 teeth is placed on the stud *D* and meshes with the 24-tooth gear *F* (see Fig. 39) on the intermediate stud. On the same intermediate stud is then placed the gear having 64 teeth, which is driven by the gear having 40 teeth placed on the feed-screw. This makes the gears having 72 and 64 teeth the driven gears, and the gears having 24 and 40 teeth the driving gears, the whole train of gears being driven from the feed-screw of the table.

In general, for compound gearing, the following formula may be used:

$$\frac{\text{lead of spiral to be cut}}{\text{lead of machine}} = \frac{\text{product of driven gears}}{\text{product of driving gears}}$$

# CHAPTER IX

## MILLING MACHINE INDEXING

The figuring of indexing movements for the dividing head of the milling machine is a subject which many mechanics think complicated, although it is really very simple. Assume that a bolt having a round head as shown in Fig. 40 is required to be milled so that the head becomes hexagonal, that is, so that it has six equal sides, as shown in Fig. 41. The index head is used for holding the work and for turning or indexing it the required amount for milling each of the six flat surfaces in turn. The index head is constructed with a worm and worm-wheel mechanism, the worm being on the crank turned when indexing, and the worm-wheel being mounted on the index spindle to which the work is attached. By moving the crank with its index pin a certain number of holes in one of the index circles, a certain angular movement can be imparted to the work. The calculating of indexing movements for the milling machine consists in finding how much the

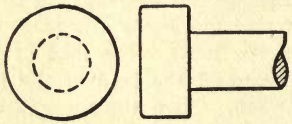


Fig. 40

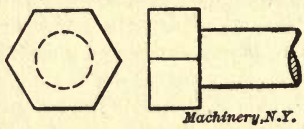


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Fig. 41

index crank requires to be turned in order to produce the required movement for indexing the work.

### Calculating the Indexing Movement

Most of the regularly manufactured index heads use a single threaded worm engaging with a worm-wheel having 40 teeth. Thus, when the index crank is turned around one full revolution, the worm is also revolved one complete turn, and this moves the worm-wheel one tooth, or 1/40 of its circumference. Therefore, in order to turn the worm-wheel and the index spindle on which it is mounted one full revolution, it is necessary to turn the index crank 40 revolutions. If we want to revolve the index spindle one-half revolution, we would have to turn the index crank 20 revolutions. If we want to turn the index spindle only one-fourth of a revolution, we turn the index crank 10 revolutions.

Suppose that we want to mill the hexagonal head of the bolt shown in Fig. 41. As it requires 40 revolutions of the index crank to revolve the index spindle once, it evidently requires only 1/6 of that number to turn the index spindle 1/6 revolution; this is the amount that the work should be turned around or indexed when one side of the hexagon has been milled, and we are ready to mill the next. Consequently, the index crank should be turned around $\frac{40}{6} = 6\ 2/3$ revolutions for milling

a hexagon; that is, we first turn the crank 6 full revolutions and then by means of the index plate we turn it 2/3 of a revolution. If we use the circle in the index plate having 18 holes, 2/3 of a revolution will mean 12 holes in this circle, as 12 is two-thirds of 18 ($12 = 2/3 \times 18$).

Assume that a piece of work has eight sides regularly spaced (regular octagon). The indexing for each side is found by dividing 40 by 8. Thus $\frac{40}{8} = 5$, represents the number of revolutions of the index crank for each side indexed and milled.

Assume that it is required to cut nine flutes regularly spaced in a reamer. The index crank must be turned $\frac{40}{9} = 4\,4/9$ revolutions in order to index for each flute. The 4/9 of a revolution would correspond to eight holes in the 18-hole circle, because $\frac{8}{18} = \frac{4}{9}$.

Assume that it is required to cut 85 teeth in a spur gear. The index crank must be revolved $\frac{40}{85} = \frac{8}{17}$ revolutions to index for each tooth. To move the index crank $\frac{8}{17}$ of a revolution corresponds to moving it 8 holes in the 17-hole circle.

As a general rule, for finding the number of revolutions required for indexing for any regular spacing, with any index head, the following rule may be used: *To find the number of revolutions of the index crank for indexing, divide the number of turns required of the index crank for one revolution of the index head spindle by the number of divisions required in the work.*

[Most standard index heads are provided with an index plate fastened directly to the index spindle for rapid direct indexing. This index plate is usually provided with 24 holes, so that 2, 3, 4, 6, 8, 12 and 24 divisions can be obtained directly by the use of this direct index plate without using the regular indexing mechanism. When using this index plate for rapid direct indexing, no calculations are required, as the number of divisions obtainable by the use of the different holes in this plate are, as a rule, marked directly at the respective holes.]

### Finding the Index Circle to Use

In order to find which index circle to use and how many holes in that index circle to move for a certain fractional turn of the index crank, the numerator and denominator of the fraction expressing the fractional turn are multiplied by the same number until the denominator of the new fraction equals the number of holes in some one index circle. The number with which to multiply must be found by trial. The numerator of the new fraction then expresses how many holes the crank is to be moved in the circle expressed by the denominator.

Assume that 12 flutes are to be milled in a large tap. Assume that 40 turns of the index crank are required for one turn of the index

head spindle. First divide 40 by 12 to find the number of turns of the index crank required for each indexing. Writing out this division as a fraction and carrying out the calculation gives us

$$\frac{40}{12} = 3\ 4/12 = 3\ 1/3.$$

The fractional turn required is 1/3 of a revolution. Now multiply, according to the rule given, the numerator and denominator of this fraction by a number so selected that the new denominator equals the number of holes in some one index circle. Multiplying by 6 would give us

$$\frac{1 \times 6}{3 \times 6} = \frac{6}{18}$$

in which fraction 18 expresses the number of holes in the index circle to use, and 6 is the number of holes the crank must be moved in this circle to turn the worm shaft and worm one-third of a revolution.

Most milling machines are commonly furnished with three index plates, each having six index circles. The following numbers of holes in the index circles of the three index plates are commonly used:

| | | | | | |
|---|---|---|---|---|---|
| 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 23 | 27 | 29 | 31 | 33 |
| 37 | 39 | 41 | 43 | 47 | 49 |

## CHAPTER X

## INDEXING FOR ANGLES

When two lines meet as shown in Fig. 42, they form an angle with each other. The point where the two lines meet or intersect is called the *vertex* of the angle. The two lines forming the angle are called the sides of the angle.

Angles are measured in degrees and subdivisions of a degree. If the circumference (periphery) of a circle is divided into 360 parts, each part is called one degree, and the angle between two lines from the center to the ends of the small part of the circle is a one-degree angle, as shown in Fig. 43. As the whole circle contains 360 degrees, one-half of a circle contains 180 degrees, and one-quarter of a circle, 90 degrees.

A 90-degree angle is called a *right* angle. An angle larger than 90 degrees is called an *obtuse* angle, and an angle less than 90 degrees is called an *acute* angle. (See Figs. 46, 47, and 48.) Any angle which is not a right angle is called an *oblique* angle.

When two lines form a right or 90-degree angle with each other, as shown in Fig. 44, one line is said to be *perpendicular* to the other.

Angles are said to be equal when they contain the same number of degrees. The angle in Fig. 49 and the angle in Fig. 50 are equal, be-

cause they are both 60 degrees; that the sides of the angle in Fig. 50 are longer than the sides of the angle in Fig. 49 has no influence on the angle because of the fact that an angle is only the *difference in direction* of two lines. The angle in Fig. 52 which contains only 30 degrees is only one-half of the angle in Fig. 49.

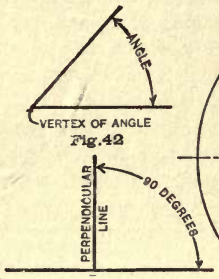


Fig. 44

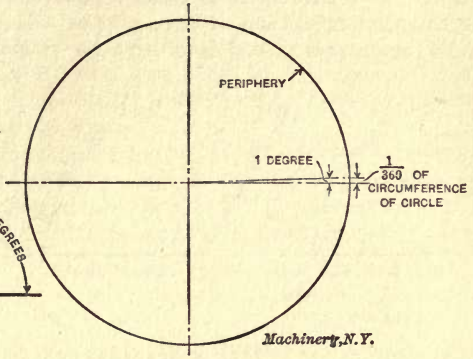


Fig. 43

One-half of a right angle is 45 degrees, as shown in Fig. 51. In Fig. 53 is shown an angle which is 120 degrees, and which can be divided into a right or 90-degree angle, and a 30-degree angle.

In order to obtain finer subdivisions for the measurement of angles than the degree, one degree is divided into 60 minutes, and one minute into 60 seconds.

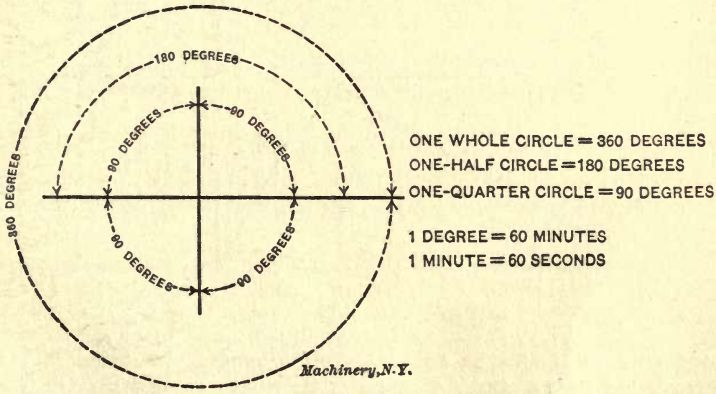


Fig. 45

Any part of a degree can be expressed in minutes and seconds, for instance, 1/2 degree = 30 minutes, 1/3 of a degree = 20 minutes; and since 1/4 of a degree = 15 minutes, 3/4 of a degree = 45 minutes. In the same way 1/2 minute = 30 seconds, 1/3 minute = 20 seconds, 1/4 minute = 15 seconds, and 3/4 minute = 45 seconds.

The word degree is often abbreviated "deg.," or the sign (°) is used to indicate degrees; thus 60° = 60 degrees. In the same way 60′ = 60 minutes (min.), 60″ = 60 seconds (sec.).

### Indexing for Angles

In Fig. 54 is shown a piece of round stock having two flats milled in such a way that the angle between two lines from the center at right angles to the two surfaces is 35 degrees. In this case the index head cannot be turned so as to make a certain whole number of moves in one complete revolution of the work, as is done, for instance, when we make four moves in one revolution for milling a square, six moves

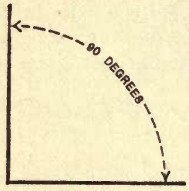


Fig. 46

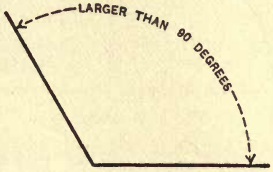


Fig. 47

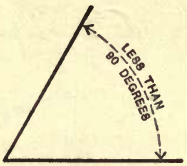


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Fig. 48

in one revolution for milling a hexagon, and 80 moves for milling an 80-tooth gear. Instead, we have here given a certain number of degrees which it is required that the work be turned before another cut is taken by the milling cutter.

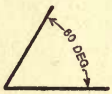



Fig. 49

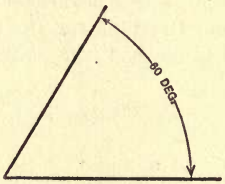



Fig. 50

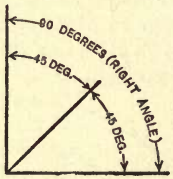



Fig. 51

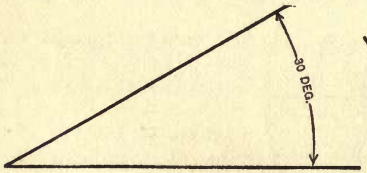
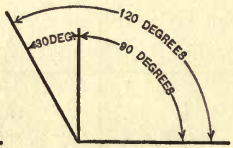



Fig. 52




*Machinery, N.Y.*

Fig. 53

Indexing for angles is only required whenever an angle is given which is not such a simple fraction of the whole circle as, for instance, 90 degrees, which is 1/4 of a complete turn, or 45 degrees, which is 1/8 of a complete turn, or 60 degrees, which is 1/6 of a complete turn; the numbers of turns of the index crank in these cases are determined as explained in Chapter IX. But if it be required to index for, say, 19 degrees, the method used is as explained in the following.

### Calculating the Movements for Angular Indexing

There are 360 degrees in one complete circle or turn, and assuming that 40 turns of the index crank are required for one revolution of the

work, one turn of the index crank must equal $\frac{360}{40} = 9$ degrees. Then, when one complete turn of the index crank equals 9 degrees, two holes in the 18-hole circle, or 3 holes in the 27-hole circle, must correspond to one degree. ($\frac{3}{27} = \frac{2}{18} = \frac{1}{9}$.) The first principle or rule for indexing for angles is therefore that two holes in the 18-hole circle or 3 holes in the 27-hole circle equals a movement of one degree of the index head spindle and the work.

Assume that an indexing movement of 35 degrees is required as shown in Fig. 54. One complete turn of the index crank equals 9 degrees; we, therefore, first divide the number of degrees for which we wish to index, by 9, in order to find how many complete turns the

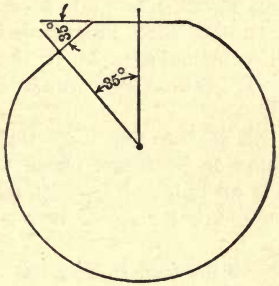



Fig. 54

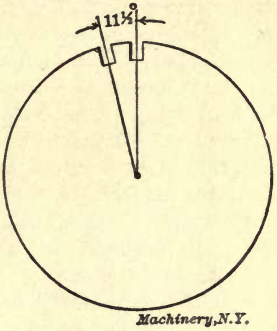



Fig. 55

index crank should make. The number of degrees left to turn when we have completed the full turns are indexed by taking two holes in the 18-hole circle for each degree. In the case in Fig. 54, $\frac{35}{9} = 3\frac{8}{9}$, which indicates that the index crank must be turned three revolutions, and then we must index for 8 degrees more or move 16 holes in the 18-hole circle.

Assume that we wish to index 11½ degrees, as shown in Fig. 55. Two holes in the 18-hole circle represent one degree, and consequently one hole represents ½ degree. To index for 11½ degrees we first turn the index crank one revolution, this being a 9-degree movement. Then to index 2½ degrees we must move the index crank 5 holes in the 18-hole circle (4 holes for the two whole degrees and one hole for the ½ degree equals the total movement of 5 holes).

Below is shown how this calculation may be carried out to plainly indicate the motion required for this angle:

11½ deg. = 9 deg. + 2 deg. + ½ deg.

1 turn + 4 holes + 1 hole in the 18-hole circle.

Should it be required to index only 1/3 degree, this may be made by using the 27-hole circle. In this circle a three-hole movement equals one degree, and a one-hole movement in that circle thus equals 1/3

degree, or 20 minutes. Assume that it is required to index the work through an angle of 48 degrees 40 minutes. First turn the crank 5 turns for 45 degrees ($5 \times 9 = 45$). Then there are 3 degrees 40 minutes or 3 2/3 degrees left. In the 27-hole circle a three-degree movement corresponds to 9 holes, and a 2/3-degree movement to 2 holes, making a total movement of 11 holes in the 27-hole circle, to complete the crank movement for 48 degrees 40 minutes. Below is plainly shown how this calculation may be carried out:

48 deg. 40 min. = 45 deg. + 3 deg. + 40 min.

5 turns + 9 holes + 2 holes in the 27-hole circle.

### Approximate Indexing for Angles

By using the 18- and 27-hole circles, only whole degrees and 1/3, 1/2, and 2/3 of a degree (20, 30, and 40 minutes) can be indexed. Assume, however, that it is required to index for 16 minutes. One whole turn of the index crank equals 9 degrees or 540 minutes ($9 \times 60 = 540$). To index for 16 minutes, therefore, requires about 1/34 of a turn of the index crank ($540 \div 16 = 34$, nearly). In this case, therefore, we use an index circle having the nearest number of holes to 34, or the index circle with 33 holes. A one-hole movement in this circle would approximate the required movement of 16 minutes.

Assume that it is required to index for 55 minutes. We then have $540 \div 55 = 10$, nearly. In this case there is no index circle with 10 or approximately 10 holes, but as there is an index circle with 20 holes, this circle will be used, and the index crank is moved two holes in that circle instead of one.

Assume that it is required to index for 2 degrees 46 minutes. If we change this to minutes we have 2 degrees $= 2 \times 60 = 120$ minutes, and 46 minutes added to this gives us a total of 166 minutes. Dividing 540 by 166 we have: $540 \div 166 = 3.253$.

Now we multiply this quotient (3.253) by some whole number, so that we obtain a product which equals the number of holes in any one index circle. The number by which to multiply must be found by trial. In this case we can multiply by 12, obtaining as a product $3.253 \times 12 = 39.036$. For indexing 2 degrees and 46 minutes we can, therefore, use the 39-hole circle, moving the index crank 12 holes.

The following is a general rule for *approximate* indexing of angles, for any index head where 40 revolutions of the index crank are required for one revolution of the work:

*Divide* 540 *by the total number of minutes to be indexed. If the quotient is approximately equal to the number of holes in any index circle, the angular movement is obtained by moving one hole in this index circle. If the quotient does not approximately equal the number of holes in any index circle, find by trial a number by which the quotient can be multiplied so that the product equals the number of holes in an available index circle; in this circle, move the index crank as many holes as indicated by the number by which the quotient has been multiplied.* (If the quotient of 540 divided by the total number of minutes is greater than the number of holes in any of the index circles, the movement cannot be obtained by simple indexing.)

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